SPAWAR
Systems Center
San Diego

TECHNICAL REPORT 1804
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NAM6: Batch Code for the Navy Aerosol Model

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ADMINISTRATIVE INFORMATION

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I thank Dr. Warren J. Wiscombe for his Mie subroutine, MIEV0, which is an indispensable part of this work.

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EXECUTIVE SUMMARY

OBJECTIVE

The objective of this project was to develop a computer program that will predict the optical consequences of the Navy Aerosol Model (NAM). The Navy Aerosol Model describes the marine aerosol close to the surface of the open ocean.

RESULTS

The sixth version of NAM (NAM6) was composed from FORTRAN code. It runs in batch mode. Each input line must contain the air mass parameter, the average wind speed during the previous 24 hours, the current wind speed, and the relative humidity. The program reads each input line, computes the particle size distribution according to version 6 of the Navy Aerosol Model, and derives the optical properties using Mie theory for spheres. Each output line contains the input parameters plus the total extinction coefficient, the extinction coefficient for scattering, and the forward lobe of the phase function. The source and executable code is available at

https://sunspot.spawar.navy.mil/543/software/

Absolute accuracy is estimated to be 5% for extinction and 10% for phase when NAM6 is run with default precision settings. In default mode, an input file of 1000 lines will execute in about 1 minute on a 333 MHz personal computer.

CONTENTS

Figures

Tables

1. INTRODUCTION

This report describes the operation of a computer program that calculates optical extinction according to the Navy Aerosol Model (Gathman, 1983). The Navy Aerosol Model is an empirical model describing the size distribution of aerosol particles close to the surface of the open ocean. The model depends on four parameters. They are: (1) p, the dimensionless air mass parameter; (2) W, the average wind speed (m s^{-1}) during the previous 24 hours; (3) w, the current wind speed (m s^{-1}); and (4) U, the relative humidity (%). These parameters completely specify dN/dr, the particle size distribution in the Navy Aerosol Model.

The information in this report refers solely to the sixth version of the Navy Aerosol Model, the version that is the kernel of the Navy Oceanic Vertical Aerosol Model (Gathman and Davidson, 1993).

2. PROGRAM OPERATION

This program is called NAM6, which stands for Navy Aerosol Model, version 6. The batch program operates sequentially on each line of an input file.[1] Each line of the input file (after the zeroth) contains a line index (which can be thought of as the time) followed by four numbers representing the values of each of the four NAM parameters. The zeroth line of the input file contains six control parameters. The first two of these are the optical wavelength in μm and the number of remaining lines in the file. Appendix A provides a sample input file with 10 input lines.

For each line of the input file, the program reads in the four parameters, computes the size distribution, and calculates, among other things, the optical extinction coefficient, β_{ext}, from the formula:

$$\beta_{ext}(\lambda) = \pi \int_0^\infty r^2 \frac{dN}{dr} Q_{ext}\, dr \quad Mm^{-1} \tag{1}$$

In this equation λ (μm) is the optical wavelength, r (μm) is the radius of the spherical aerosol particle, and Q_{ext} (dimensionless) is the Mie efficiency factor for extinction. The Mie efficiency factor (van de Hulst, 1981) is the ratio between the optical and physical cross-sections of the particle. The Mie factors are computed in a subroutine called MIEV0 (Wiscombe, 1979) written by Warren J. Wiscombe and obtained from him via the Internet.

The program prints this result (as well as two others) to a single line of an output file along with the input parameters that were used for that particular calculation. The output file is called "Out.txt." Appendix B provides a sample output file corresponding to the input file in Appendix A.

[1] We refer to lines of the input file starting with the zeroth line, the control line. With this convention, the first active line (the first one to contain model parameters) is called "the first line."

3. PROGRAM SPEED

Since this is a batch program that might conceivably operate on an input file containing many hundreds or even a thousand lines, execution time is an important consideration. For large input files, the Mie calculation in subroutine MIEV0 determines the execution time. On a Pentium II processor running at 333 MHz with 64 MB of RAM, each call to MIEV0 takes about 55 μs. When NAM6 runs with default precision, each input line requires 771 calls for $p \leq 5$ and 1028 calls for $p > 5$. Hence, at the rate of 55 μs per call, each line with $p \leq 5$ would take 42 ms and each line with $p > 5$ would take 57 ms. Applying this rule to the sample input file of Appendix A, I find that 8995 calls to MIEV0 are required and predict that the calculation would take 495 ms. The actual time for this input file was 550 ms. I consider this in good agreement with the estimate because the operating system (Windows 98) probably required significant overhead.

Under default conditions, NAM6 will take about 1 minute to execute an input file of 1000 lines on a 333 MHz machine.

4. THE SIZE DISTRIBUTION

In the Navy Aerosol Model, particles have radii that are distributed according to a lognormal law (Evans et al., 1993). Various properties of the lognormal distribution and its use in the context of aerosol technology are further described by Hinds (1982).

Let there be N particles per cubic centimeter regardless of radius. Then the aerosol sizes in this model are distributed according to

$$\frac{dN}{dr} = N\, f(r) \quad cm^{-3}\, \mu m^{-1}, \tag{2}$$

where

$$\begin{aligned} f(r) &= \frac{1}{\sqrt{2\pi}\,\sigma\, r} \exp\left\{ -\frac{[\ln(r/m)]^2}{2\sigma^2} \right\} \quad \mu m^{-1} \\ &= \frac{1}{\sqrt{2\pi}\,\sigma \exp(\sigma^2/2)\rho} \exp\left\{ -\frac{[\ln(r/\rho)]^2}{2\sigma^2} \right\} \quad \mu m^{-1} \end{aligned} \tag{3}$$

and

$$\int_0^\infty f(r)\,dr = 1. \tag{4}$$

In equation (3), σ, the shape parameter, and ρ, the mode, completely determine the distribution function, f. Furthermore, the median, m, is related to the mode by

$$m = \rho \exp(\sigma^2) \quad \mu m \tag{5}$$

The Navy Aerosol Model assumes that

$$\sigma = 1/\sqrt{2} \tag{6}$$

The distribution, *dN/dr,* is therefore completely specified by the values chosen for N and ρ. The concentration depends on the parameters p, W, and w. The mode depends on the relative humidity, U. These dependencies will be described after I introduce further details of the Mie calculation previewed in equation (1).

In the code, it proved convenient to separate the size distribution into two parts: one that depended on particle radius, and one that did not. Hence, inside the code, a constant α appears such that

$$\frac{dN}{dr} = \alpha \exp\left\{ -[\ln(r/\rho)]^2 \right\} \quad cm^{-3}\ \mu m^{-1}, \tag{7}$$

where

$$\alpha \equiv \left.\frac{dN}{dr}\right|_{r=\rho} = \frac{1}{\sqrt{\pi}\exp(1/4)}\frac{N}{\rho} \quad cm^{-3}\ \mu m^{-1}. \tag{8}$$

Figure 1 shows how the size distribution and its second moment depend on particle radius for a distribution with a concentration of 1 particle per cm^3, a mode of 0.24 μm, and a shape parameter of $1/\sqrt{2}$.

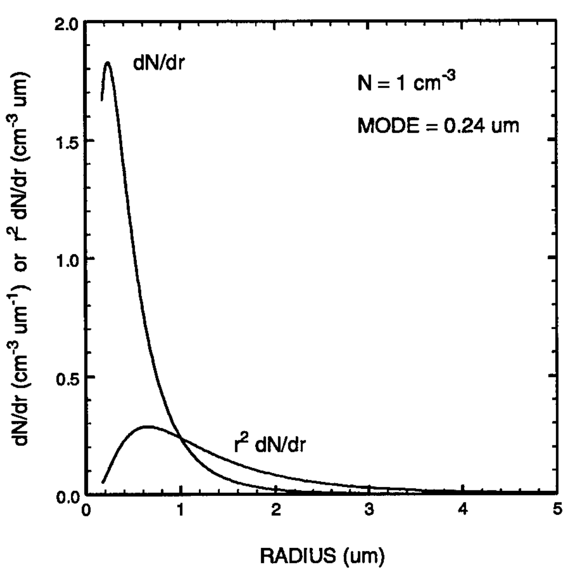

Figure 1. The log normal size distribution and its second moment. They are drawn for a distribution with a mode of 0.24 μm, a shape parameter of $1/\sqrt{2}$, and a concentration of 1 particle per cm^3.

5. OPTICAL PROPERTIES OF THE SIZE DISTRIBUTION

Given a size distribution of aerosol particles, the optical properties are calculated by integrating the Mie results for a monodispersion over all the radii represented in the polydispersion. I am interested in three optical properties: the total extinction coefficient, β_{ext}; the extinction coefficient for scattering, β_{sca}; and the forward lobe of the phase function, $\Phi(0)$. These are given by the following integrals over the size distribution:

$$\beta_{ext}(\lambda)=\pi\int_0^\infty r^2\frac{dN}{dr}Q_{ext}(x,m)\,dr \quad Mm^{-1} \tag{9}$$

$$\beta_{sca}(\lambda)=\pi\int_0^\infty r^2\frac{dN}{dr}Q_{sca}(x,m)dr \quad Mm^{-1} \tag{10}$$

$$\Phi(\theta)=\frac{1}{k^2\beta_{sca}}\int_0^\infty\frac{dN}{dr}|S(\theta,x,m)|^2dr \quad sr^{-1} \tag{11}$$

These formulas[2] hold for incident natural (unpolarized) light. In these equations, the optical wave number is

$$k\equiv 2\pi/\lambda \quad \mu m^{-1} \tag{12}$$

the Mie size parameter is

$$x\equiv k\,r \tag{13}$$

and the complex optical index of the particle material is

$$m\equiv n-i\,n' \tag{14}$$

The phase function in equation (11) has been defined such that its integral over all angles is 1:

$$\int_0^{4\pi}\Phi(\theta)d\omega=1. \tag{15}$$

[2] In this set of equations, and when we refer to Mie quantities in the rest of this report, we use the notation of van de Hulst with the following exceptions: we use r (rather than a) for the particle radius, and we use β (rather than γ) for the extinction coefficients.

With this normalization of the phase function, $\Phi(\theta)d\omega$ is the fraction of radiation that is scattered into a solid angle, $d\omega$, about an angle, θ, relative to the incident radiation.

When the subroutine MIEV0 is supplied with the parameters x ("X" in the code) and m ("CREFIN"), it returns the values of Q_{ext} ("QEXT"), Q_{sca} ("QSCA"), and S (0, x, m) ("SFORW"). These three returns are integrated over particle radius inside a loop over the radius index K. The integration over particle radius occurs in steps that are equally spaced on a logarithmic scale. The steps start and stop in such a way that the accuracy of the second moment of the lognormal distribution can be determined. The details of these steps and their limit are further described in section 9, "Accuracy."

Figure 2 shows the optical properties, at a wavelength of 3.5 μm, as a function of particle radius. These optical properties are given by Mie theory, according to the subroutine MIEV0, for an optical index corresponding to a particle of sea salt mixed with water at a relative humidity of 80%.

The optical properties (at 3.5 μm) of the polydispersion shown in figure 1 are given by the area under the product of the appropriate curves in figures 1 and 2.

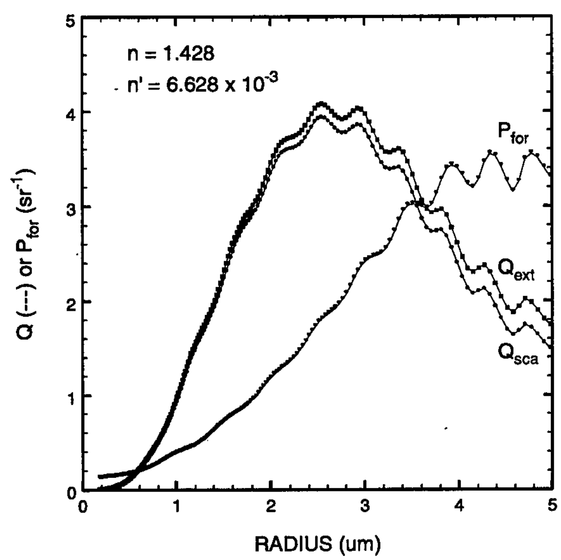

Figure 2. Optical properties of spherical particles as a function of particle radius according to Mie theory. The optical indices pertain to a particle made from a mixture of sea salt and water at 80% relative humidity. The optical wavelength is 3.5 μm.

6. PARTICLES AND THEIR GROWTH

There are four different kinds of aerosol particle in the Navy Aerosol Model. Each particle has its own neutral[3] mode and each particle grows differently in response to changes in relative humidity. Particle 0 is dust with a mode of 0.03 μm. Particle 1 is Volz' B1 aerosol material mixed with water (Volz, 1972) with a neutral mode of 0.03 μm. Particle 2 is sea salt mixed with water with a neutral mode of 0.24 μm. Particle 3 is sea salt mixed with water with a neutral mode of 2.00 μm.

The dust does not grow in response to changes in relative humidity. All the rest of the particles do grow, however. Their growth (Gerber, 1985) is governed by the following equations:

$$
\begin{aligned}
s &\equiv U/100 \\
\rho &= \rho(s) = g(s)P \quad \mu m \\
g(s) &\equiv \left[\frac{A-s}{B(1-s)}\right]^{1/3} \\
g(0.8) &= 1
\end{aligned}
\tag{16}
$$

In equation (16) the parameter s, sometimes called the saturation index, is merely the relative humidity expressed as a fraction rather than as a percent. The constants, A and B, are chosen such that the growth function, g, is equal to 1 under neutral conditions. Hence, the constant P gives the mode under neutral conditions.

For each particle, table 1 lists the neutral mode as well as the individual values for the Gerber growth constants, A and B. Figure 3 shows how each of the three particles responds to changes in the relative humidity. This figure has been drawn using equation (16) and the values of growth constants in table 1.

Table 1. Aerosol particles appearing in NAM6.

Particle	Material	P (μm)	A	B	Range
0	Dust	0.03	----	----	----
1	B1 + Water	0.03	1.17	1.87	$s < 0.99$
2	Salt + Water	0.24	1.83	5.13	$s < 0.999$
3	Salt + Water	2.00	1.97	5.83	$s < 0.9999$

[3] "Neutral" refers to a relative humidity of 80%, which is common over the open ocean.

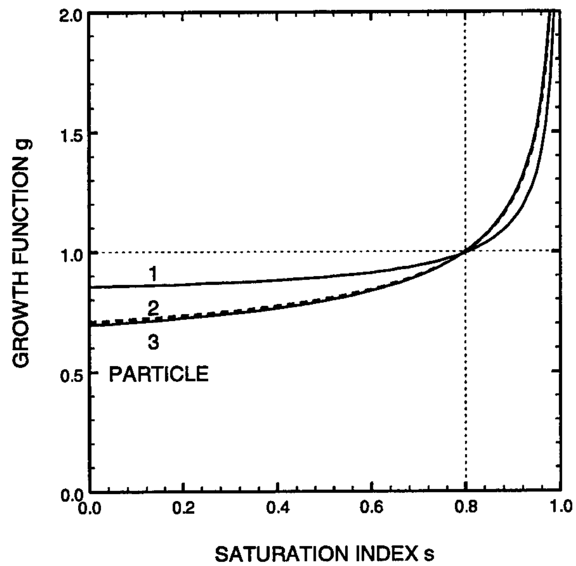

Figure 3. Growth factors, given by equation (16) and table 1, for three particles in the Navy Aerosol Model that change size in response to changes in the relative humidity. The dashed lines indicate the neutral condition.

7. OPTICAL INDICES

The aerosol particles in the Navy Aerosol Model are made up of different combinations of four materials. These materials are (1) dust, (2) B1 aerosol, (3) sea salt, and (4) water. Table 2 associates each of the materials with a value of the parameter, *M*, that appears in the code.

Table 2. Names, values of *M*, and references to the optical index for the four materials that make up the NAM6 aerosol particles.

Material	*M*	Reference
Dust	1	Shettle and Fenn (1979)
B1	2	Volz (1972)
Sea Salt	3	Shettle (1979)
Water	4	Hale and Query (1973)

The only material property entering into the computation is the optical index m. The optical indices of each material have been taken from the literature references in table 2 at optical wavelengths between 0.2 and 40 μm. Figures 4 through 11 show the indices. The numerical values for these indices are available in three locations: (1) the original literature, (2) appendices to this report, and (3) in the code for the subroutine "Block Data Optical," also in an appendix to this report. For optical wavelengths that do not match tabulated values, NAM6 interpolates linearly between tabulated values.

Particles are mixed together by volume interpolation between indices (Hänel, 1975). The following equation gives the volume interpolation:

$$m = m_w + (m_o - m_w)\frac{g^3(0)}{g^3(s)}, \qquad (17)$$

where m_o is the index of the pure (completely dry) material and m_w is the index of water.

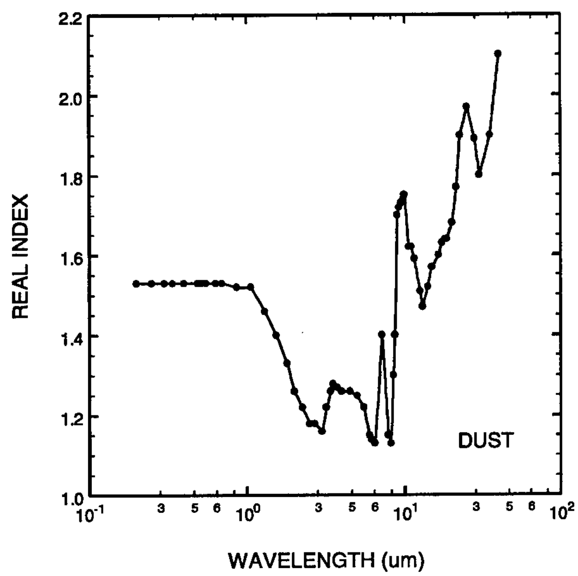

Figure 4. The real part of the optical index for dust as a function of optical wavelength. The solid circles are tabulated values from the literature, and the lines connecting them were generated by linear interpolation within the NAM6 code.

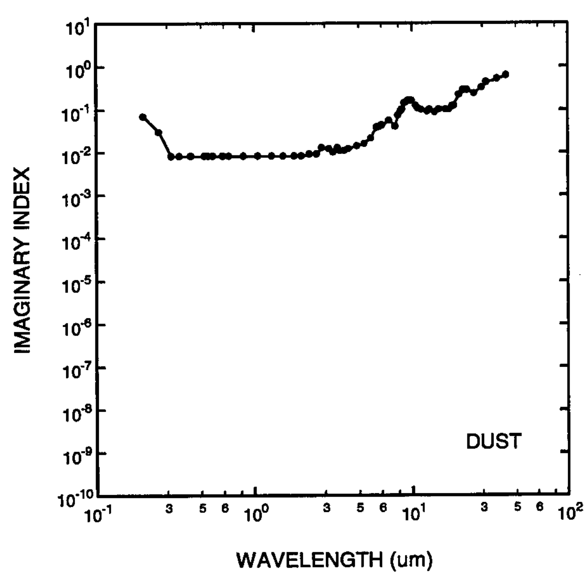

Figure 5. The imaginary part of the optical index for dust as a function of optical wavelength. The solid circles are tabulated values from the literature, and the lines connecting them were generated by linear interpolation with the NAM6 code.

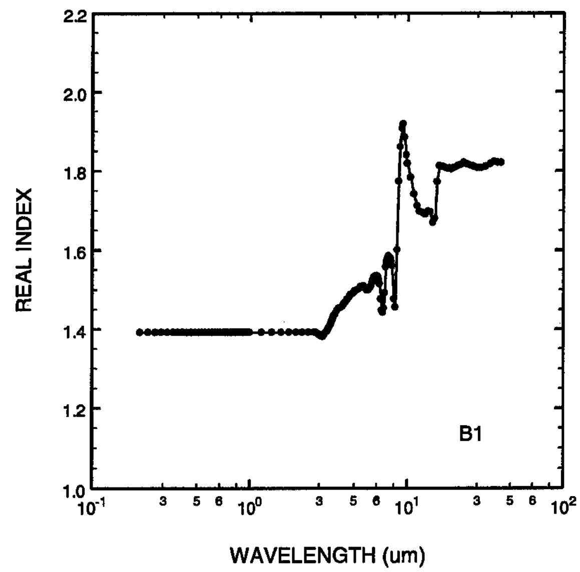

Figure 6. The real part of the optical index for B1 aerosol.

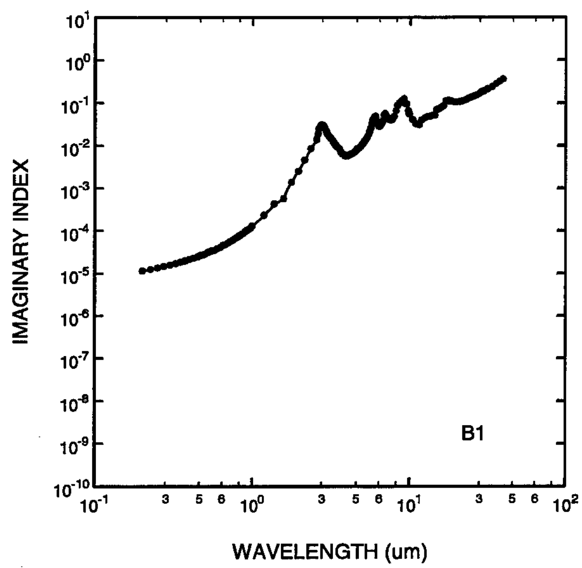

Figure 7. The imaginary part of the optical index for B1 aerosol.

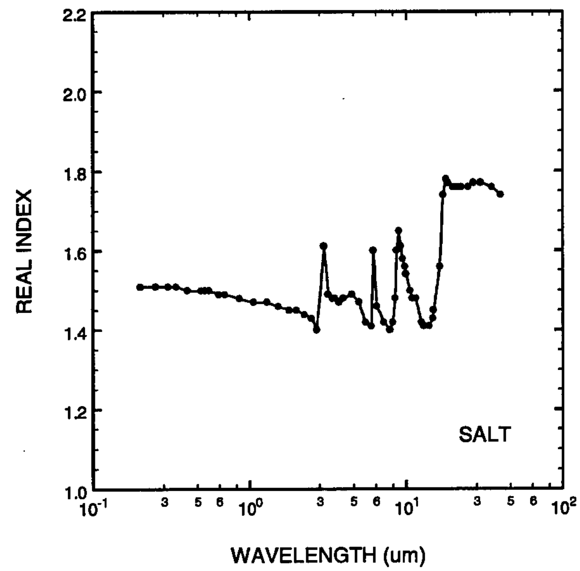

Figure 8. The real part of the optical index for sea salt.

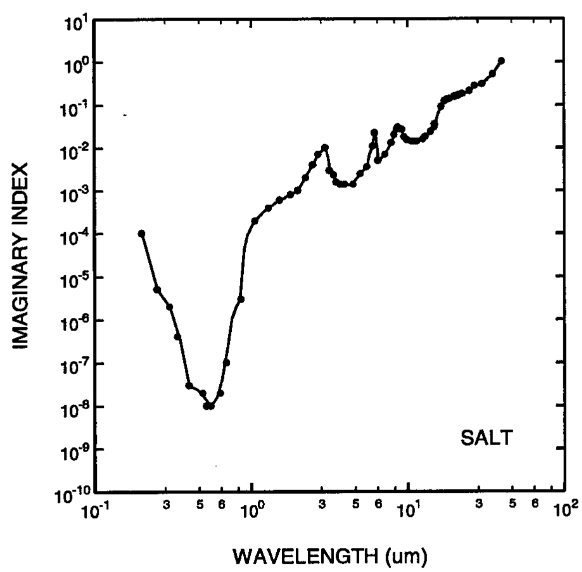

Figure 9. The imaginary part of the optical index for sea salt.

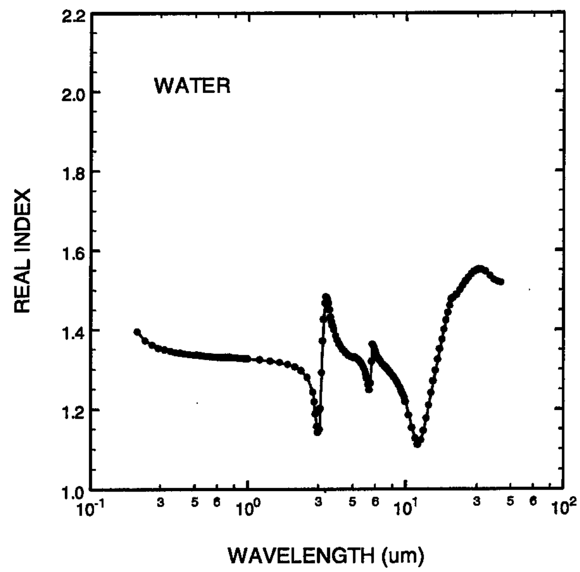

Figure 10. The real part of the optical index for water.

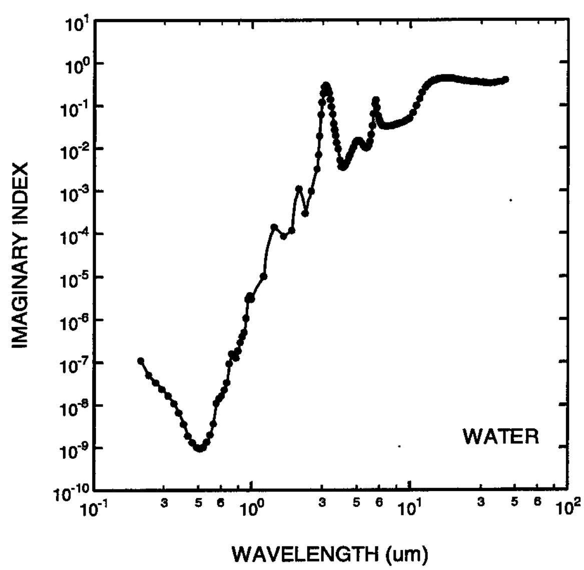

Figure 11. The imaginary part of the optical index for water.

8. PARTICLE CONCENTRATION

Of the four empirical parameters that control the Navy Aerosol Model, humidity determines particle growth through equation (16). Humidity plays no part in determining the particle concentration; that role is left to the remaining three parameters, p, W, and w.

The concentrations are given by the following set of equations:

$$
\begin{aligned}
&When\ \ p \leq 5, \\
&\qquad N_o = 0 \qquad cm^{-3} \\
&\qquad N_1 = 136.55\ p^2 \qquad cm^{-3} \\
&When\ \ p > 5, \\
&\qquad N_o = 0.3 \times 136.55\ p^2 \qquad cm^{-3} \\
&\qquad N_1 = 0.7 \times 136.55\ p^2 \qquad cm^{-3} \\
&N_2 = 0.5462 \times Max\{5.866(W - 2.2),\ 0.5\} \qquad cm^{-3} \\
&N_3 = 4.5518 \times 10 \wedge \{0.06w - 2.8\} \qquad cm^{-3},
\end{aligned}
\tag{18}
$$

where the concentration subscript refers to the particle number.[4]

9. ACCURACY

We are aware of two features that influence the accuracy of the final result: (1) Mie self-similarity, and (2) integration precision.

The first feature is one that I know very little about, namely, the self-similar behavior of the Mie factors returned by MIEV0. Wiscombe (1979) informs me that the wiggles in the optical properties (shown in rather mild form in figure 2) may become sharper under certain circumstances. When this happens, the sharp peaks will lead to an overestimate of the integral because the spikes may set the height of a relatively broad radius step during the application of Simpson's rule. Wiscombe reports that finer step spacing will not solve this problem. The reason he gives is that the spikes persist at all scale sizes; they are an example of self-similarity. I am unfamiliar with this behavior and have simply ignored it. Wiscombe further reports that agreement to within several percent between different Mie codes and calculation methods should be regarded as very good agreement.

The second feature influencing accuracy is the precision of the radius steps for those integrands that are smooth functions of particle radius. This is a feature that I have done something about. The ideal in precision would be very closely spaced steps that span the entire area under the integrands of equations (9), (10), and (11). However, that would take too long for a batch process, so a trade-off must be made in which precision is sacrificed for speed.

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[4] In the code, the particle number is associated with an integer parameter, J, that is larger by 1 than the particle number itself. In other words, in the code, particle 0 has $J = 1$, particle 1 has $J = 2$, and so forth.

To approach the problem of step precision, I have focussed on the second moment of the lognormal, which is about as close as I can come to the final result (apart from a factor of π) when I ignore the Mie factor. The second moment is given by

$$\int_0^\infty r^2 f(r)dr = (\rho e)^2 \quad \mu m^2, \tag{19}$$

where

$$f(r) \equiv \frac{1}{\sqrt{\pi}\exp(1/4)\rho}\exp\{-[\ln(r/\rho)]^2\} \quad \mu m^{-1} \tag{20}$$

since I have adopted the NAM value for the shape parameter. The mode and median of the second moment are

$$\begin{aligned} \rho_2 &= \rho e \quad \mu m \\ m_2 &= \rho e^{3/2} \quad \mu m, \end{aligned} \tag{21}$$

where ρ is the mode of the zeroth moment (as before) and e is the natural logarithm.

Since it would take a very long time to integrate all the way from zero to infinity, I evaluate a truncated version of the second moment:

$$\int_a^b r^2 f(r)\,dr \qquad \mu m^2. \tag{22}$$

The error introduced by truncation is

$$\tau \equiv \frac{1}{2}\{erfc(\ln[m_2/a]) + erfc(\ln[b/m_2])\}. \tag{23}$$

I choose to make the two terms in equation (23) equal. This means that the area lost at the low end of the second moment (the integral from 0 to a) is equal to the area lost at the high end (the integral from b to ∞). With this choice, for any given truncation loss, τ, I will have the following values for the truncation limits:

$$\begin{aligned} a &= m_2 \exp(-z) \quad \mu m \\ b &= m_2 \exp(+z) \quad \mu m \\ z &\equiv erfc^{-1}(\tau). \end{aligned} \tag{24}$$

These equations mean that ln a is z below ln m_2, ln b is z above ln m_2, and the span between them is 2 z. Figure 12 shows how truncation loss depends on z; it is just erfc (z). The user may choose the value of z; It is the last entry on the zeroth line of the input file. If a non-zero value is not explicitly entered

there, the program uses a default value of 1.8. The default choice corresponds to a truncation loss of 1%.

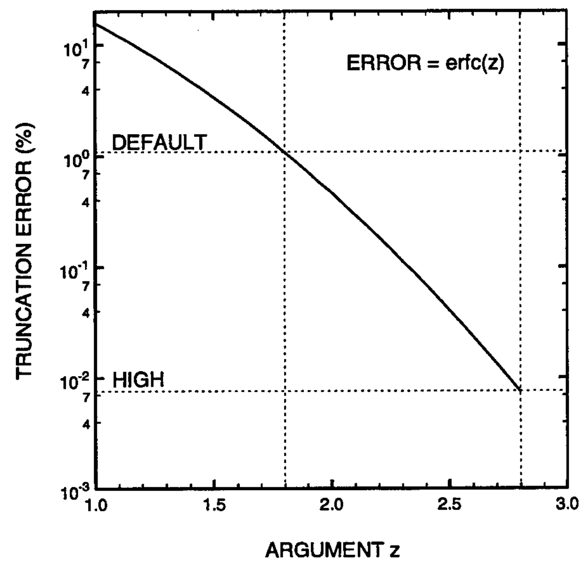

Figure 12. Truncation loss as a function of *z*, the argument of the complementary error function. The dashed lines show the default setting. The solid line is terminated at the maximum value for *z* (2.8) allowed by the program. When *z* is at this maximum, the truncation error is 0.008%.

Step spacing still needs to be discussed. After some experimentation with equally spaced steps in particle radius, I switched to equally spaced steps in the logarithm of the radius. The logarithmic steps are forced to span almost the entire area under the second moment. Specifically, they are forced to span the distance between $\ln a_{\min}$ and $\ln b_{\max}$, where

$$\begin{aligned} \ln a_{\min} &\equiv \ln\rho + \frac{3}{2} - 2.8 \\ \ln b_{\max} &\equiv \ln\rho + \frac{3}{2} + 2.8 \end{aligned} \tag{25}$$

Regardless of their number, the steps will always span the same distance of 5.6 in $\ln r$ (a factor of 270 in r). That distance has the negligible truncation loss for the second moment of

$$erfc(2.8) = 0.008\% \tag{26}$$

The total number of steps ("Kmax" in the code) for this span is also at the discretion of the user. The number of steps may be entered as the next-to-last parameter on the zeroth line of the input file. If the user does not explicitly enter a value in that location, the program uses a default value of 400 steps in ln *r*.

Figure 13 shows how the step precision influences the value of the second moment.

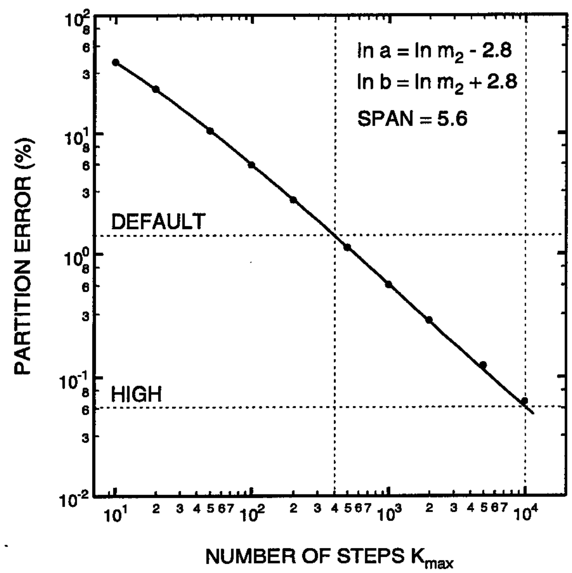

Figure 13. Partition loss as a function of K_{max}, the number of equal steps in ln *r* to span the fixed distance of 5.6. The solid circles represent program runs; the solid line is given by equation (27). The dashed lines show the default setting. The program limits the range of K_{max} to that of the solid line, namely, 10 to 10^4.

The solid circles are the per cent error in the second moment, ξ, obtained by running NAM6 with different values for Kmax. (Recall that the value of the second moment is precisely known from equation [19].) The line is an empirical fit to the solid circles given by the relationship

$$\xi = \frac{1000}{c + d\,K_{max}} \quad \%$$
$$c = 7.3194 \qquad (27)$$
$$d = 1.7687$$

I call ξ the precision loss to distinguish it from τ, the truncation loss. The program sets the step spacing to

$$\Delta \ln r \equiv \frac{5.6}{K_{max}} \qquad (28)$$

and then truncates the steps below a and above b. With this arrangement, truncation does not affect spacing and I am able to say that the total loss (or error), ε, is the sum of the partition loss and the truncation loss:

$$\varepsilon = \tau + \xi . \tag{29}$$

Of course, this discussion pertains only to the second moment; the loss for the full integral (involving the Mie factor in the integrand) will not be related in any particular way to these errors.

With default settings, 400 logarithmic steps span the distance of 5.6 and 143 of those steps are dropped for a final span of 3.6. The total second moment loss is 2.4% of which 1.4% is partition loss and 1% is truncation loss.

These steps are applied separately to each of the NAM particles. Since there are three particles for low values of air mass parameter and four particles for high values, there are either 3 x 287 = 771 steps or 4 x 287 = 1028 steps required under default precision. This sets the default computation speed as previously discussed.

Given my lack of knowledge about the role of self-similarity in Mie calculations such as these, it is difficult for me to assign an overall accuracy to NAM6 with any certainty. Guided by Wiscombe's remarks on the Mie spikes, the Mie self-similarity error will probably be about equal to my default precision error, and I adopt the conservative position that these two very different errors will add.

Hence, my opinion is that the absolute accuracy of NAM6 is somewhere in the neighborhood of 5%.

10. TEST CASES

I present results of four test cases in this section to compare NAM6 with another version of the Navy Aerosol Model. The results are presented in a form that will allow future comparison with nominally identical codes. I list these results to four and five significant figures (in spite of the relatively low absolute accuracy of the code) to facilitate easy intercomparison between codes.

The four cases are "Low Vis," "Low IR," "High Vis," and "High IR." The first word refers to the sea condition and the second word refers to the optical wavelength. These words are precisely defined in table 3.

Table 3. Test case definitions.

Optical	λµm	Sea	ρ (--)	W (m s^{-1})	w (m s^{-1})	U (%)
Vis	0.55	Low	1	1	1	50
IR	10.591	High	10	10	10	95

Each case was run for two precision settings: default and high. For high precision, I chose

$$\begin{aligned} K_{\max} &= 10{,}000 \\ z &= 2.8, \end{aligned} \tag{30}$$

for which the total second moment loss was 0.06%.

For each of the default test cases, figures 14 through 27 show the shapes of the second moment, the Mie efficiency factor for extinction, and their product. Mie spikes are prevalent in many of the visible, low sea figures.

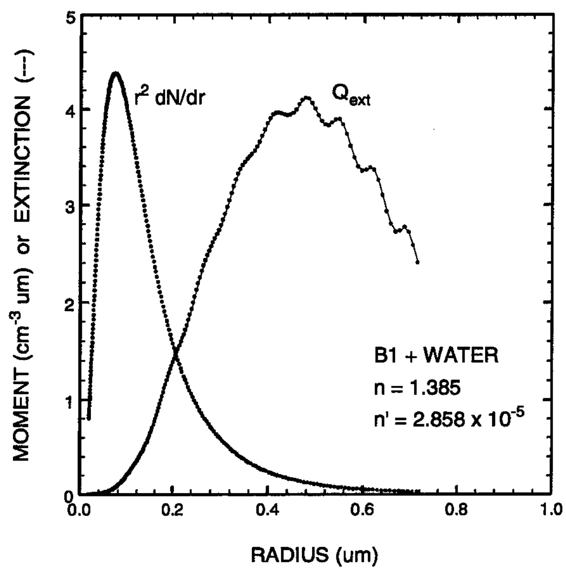

Figure 14. Second moment and Mie extinction factor for particle 1 under visible low conditions. These curves were generated with default precision. There is one point for each radius step.

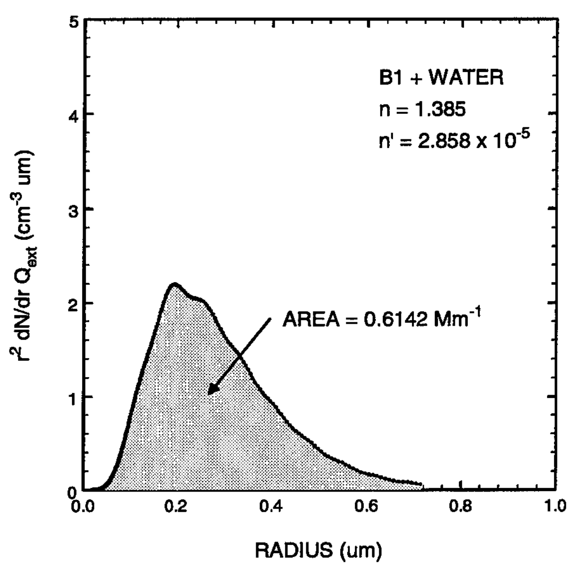

Figure 15. The product of the two curves shown in the previous figure. The area under the curve, when multiplied by π, is the optical extinction

at 0.55 μm due to particle 1.

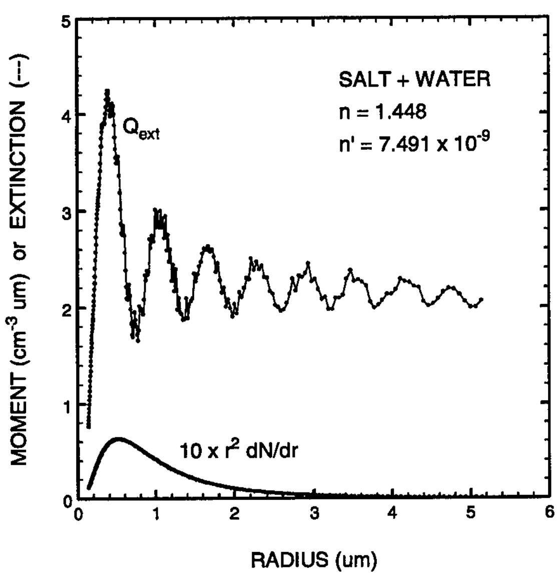

Figure 16. Second moment and Mie extinction factor for particle 2 under visible low conditions.

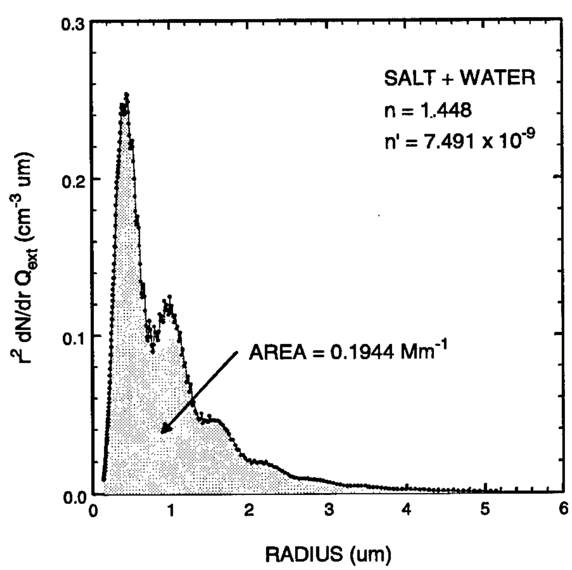

Figure 17. The product of the two curves shown in the previous figure. The area under the curve, when multiplied by π, is the optical extinction at 0.55 μm due to particle 2.

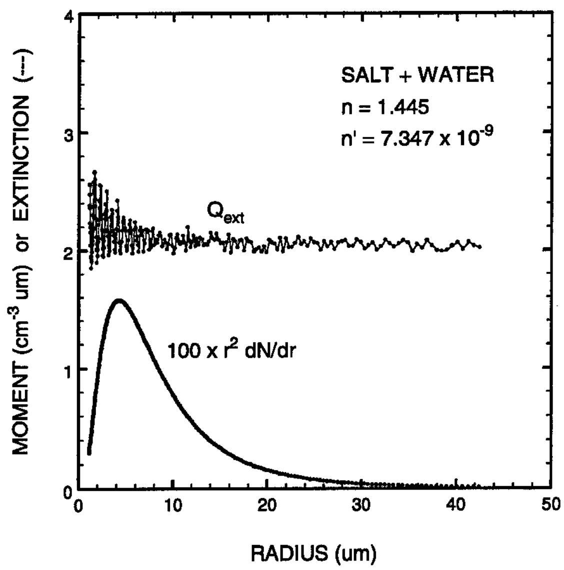

Figure 18. Second moment and Mie extinction factor for particle 3 under visible low conditions.

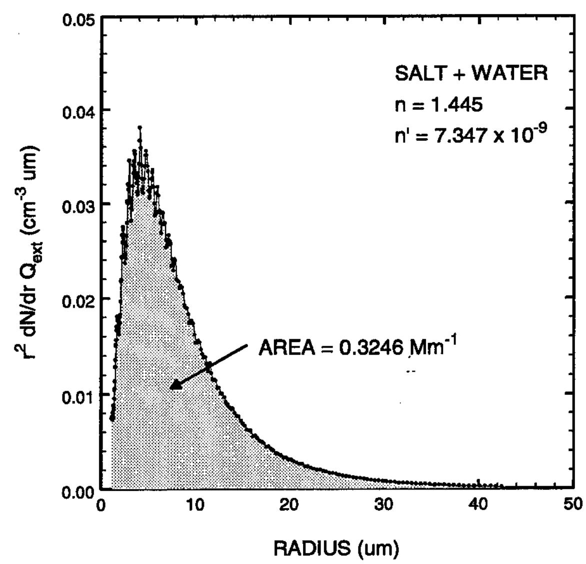

Figure 19. The product of the two curves shown in the previous figure. The area under the curve, when multiplied by π, is the optical extinction at 0.55 μm due to particle 3.

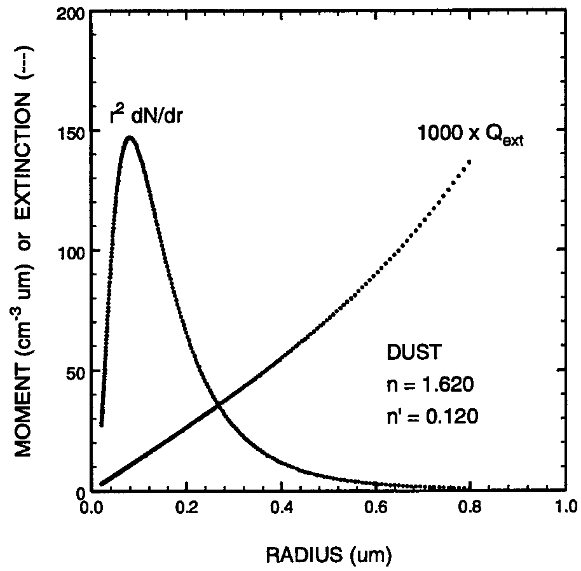

Figure 20. Second moment and Mie extinction factor for particle 0 under infrared high conditions. These curves were generated with default precision. There is one point for each radius step.

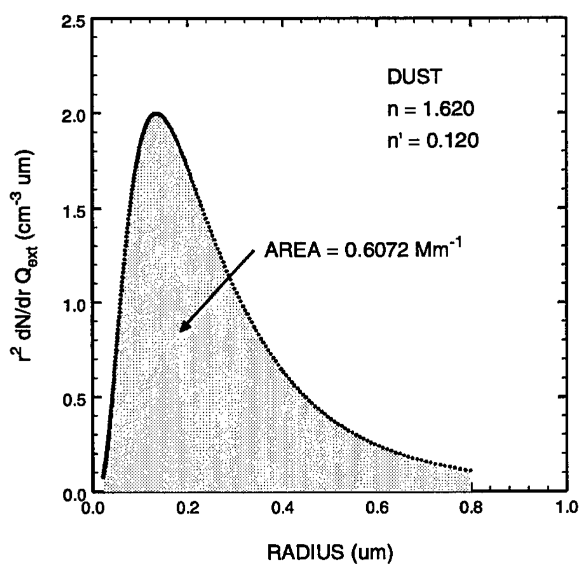

Figure 21. The product of the two curves shown in the previous figure. The area under the curve, when multiplied by π, is the optical extinction at 10.591 μm due to particle 0.

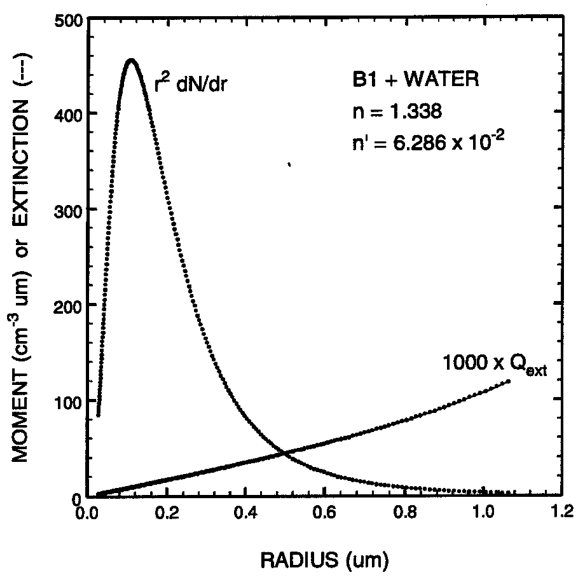

Figure 22. Second moment and Mie extinction factor for particle 1 under infrared high conditions.

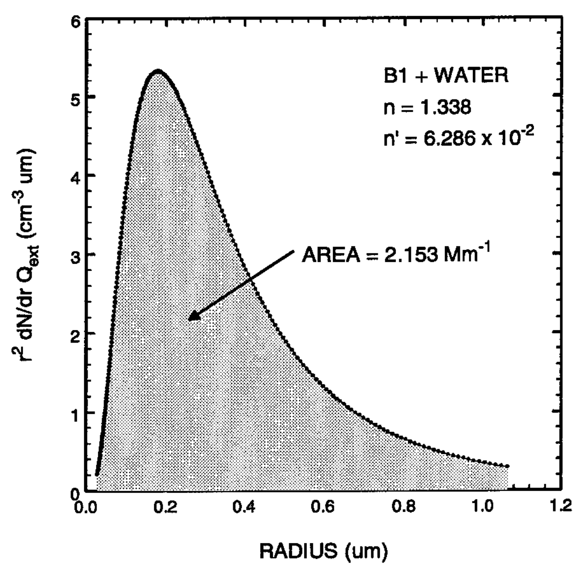

Figure 23. The product of the two curves shown in the previous figure. The area under the curve, when multiplied by π, is the optical extinction at 10.591 μm due to particle 1.

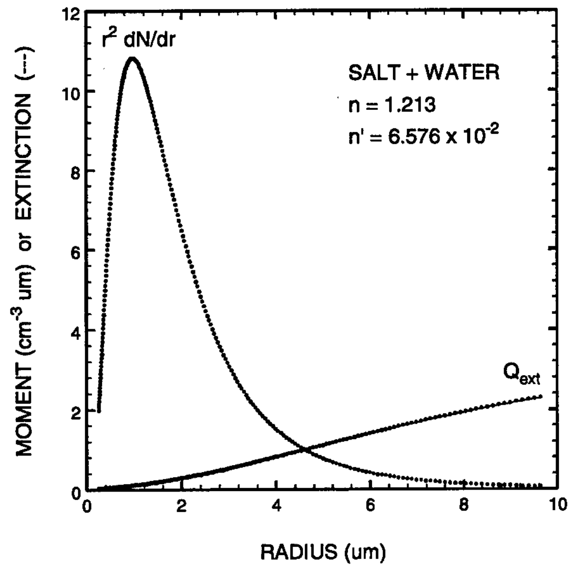

Figure 24. Second moment and Mie extinction factor for particle 2 under infrared high conditions.

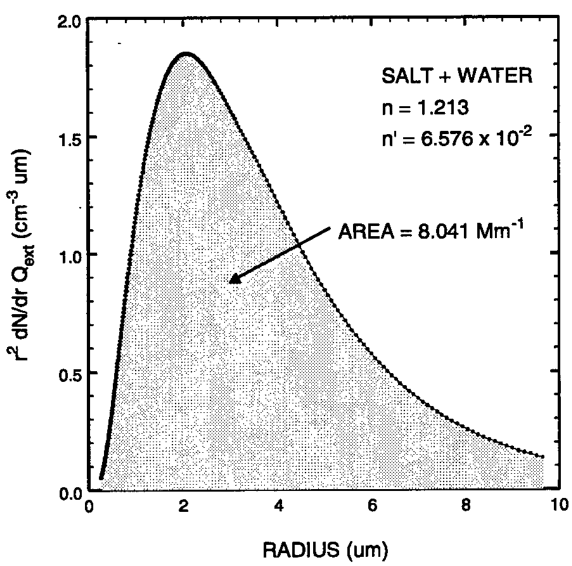

Figure 25. The product of the two curves shown in the previous figure. The area under the curve, when multiplied by π, is the optical extinction at 10.591 μm due to particle 2.

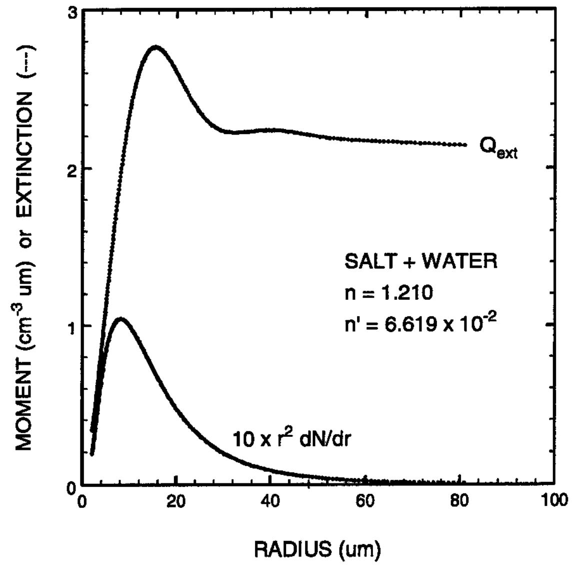

Figure 26. Second moment and Mie extinction factor for particle 3 under infrared high conditions.

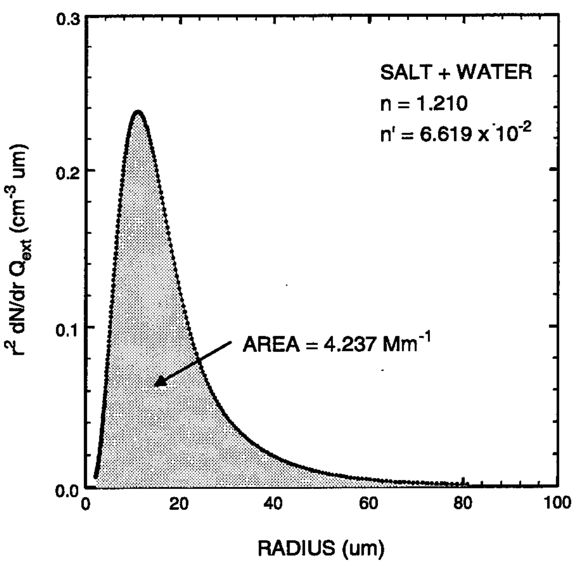

Figure 27. The product of the two curves shown in the previous figure. The area under the curve, when multiplied by π, is the optical extinction at 10.591 μm due to particle 3.

In tables 4, 5, and 6, numerical test results are given to four significant figures. The phase function is much more sensitive than the extinction to precision. In fact, the default phase function is about 11% below the high-precision phase function. This indicates that my accuracy estimate of 5% is far too optimistic for the forward lobe of the phase function.

Table 4. Test case results for NAM6. High precision is defined by equation (30).

Sea	λ	Precision	β_{ext} (Mm^{-1})	β_{sca} (Mm^{-1})	Φ (0) (sr^{-1})
Low	Vis	Default High	3.560 3.604	3.560 2.604	647.9 730.1
Low	IR	Default High	1.228 1.240	0.9454 0.9529	37.33 4.198
High	Vis	Default High	772.3 780.0	766.6 774.1	2340 2646
High	IR	Default High	47.25 48.96	17.27 18.17	14.32 16.18

Table 5. Log-normal parameters and values of extinction associated with low sea test case. Results are given for each of three NAM6 particles (particle 0 does not exist under low sea conditons). Extinction was calculated with high precision.

λ	Quantity	Particle 1	Particle 2	Particle 3	Sum	Unit
---	α	2.235×10^{3}	6.224×10^{-1}	2.286×10^{-3}	---	$cm^{-3}\,\mu m^{-1}$
---	N	1.366×10^{2}	2.731×10^{-1}	8.283×10^{-3}	---	cm^{-3}
---	ρ	2.685×10^{-2}	1.928×10^{-1}	1.592×10^{0}	---	μm
Visible	n	1.385	1.448	1.445	---	---
Visible	n'	2.855×10^{-5}	7.491×10^{-9}	7.347×10^{-9}	---	---
Visible	β_{ext}	1.958×10^{0}	6.139×10^{-1}	1.032×10^{0}	3.604	Mm^{-1}
Infrared	n	1.700	1.400	1.394	---	---
Infrared	n'	4.251×10^{-2}	3.203×10^{-2}	3.306×10^{-2}	---	---
Infrared	β_{ext}	1.675×10^{-2}	4.059×10^{-2}	1.182×10^{0}	1.240	Mm^{-1}

Table 6. Log-normal parameters and values of extinction associated with the high sea test case. Results are given for each of the four NAM6 particles. Extinction was calculated with high precision.

λ	Quantity	Particle 0	Particle 1	Particle 2	Particle 3	Sum	Unit
---	α	6.000×10^{4}	1.053×10^{5}	3.034×10^{1}	4.156×10^{-3}	---	$cm^{-3}\,\mu m^{-1}$
---	N	4.097×10^{3}	9.559×10^{3}	2.499×10^{1}	2.872×10^{-2}	---	cm^{-3}
---	ρ	3.000×10^{-2}	3.990×10^{-2}	3.620×10^{-1}	3.036×10^{0}	---	μm
Visible	n	1.530	1.349	1.350	1.349	---	---
Visible	n'	8.000×10^{-3}	8.697×10^{-6}	2.796×10^{-9}	2.736×10^{-9}	---	---
Visible	β_{ext}	1.265×10^{2}	4.590×10^{2}	1.816×10^{2}	1.277×10^{1}	780.0	Mm^{-1}
Infrared	n	1.620	1.338	1.213	1.210	---	---
Infrared	n'	1.200×10^{-1}	6.286×10^{-2}	6.576×10^{-2}	6.619×10^{-2}	---	---
Infrared	β_{ext}	2.021×10^{0}	7.153×10^{0}	2.639×10^{1}	1.340×10^{1}	48.96	Mm^{-1}

So much for the results obtained with NAM6. The high-precision NAM6 results are next compared with the results of a similar code in table 6. "Tables" are results derived from entries in the source code tables for NOVAM (Gathman and Davidson, 1993, pp. 92 ff.). However, the NOVAM tables are not directly related to extinction. I assumed that the following relationship held for a table entry, T, in the NOVAM array "TJQext:"

$$\begin{aligned} 10\wedge T\,(J,\lambda) &= \int_0^\infty r^2 \exp\left\{-\left[\ln\left(r/\rho[J]\right)\right]^2\right\} dr \\ &= \frac{\beta_{ext}(J,\lambda)}{\pi\,\alpha(J)}, \end{aligned} \tag{31}$$

where the index, J, refers to the particle. That is, the values in the column "Tables" of table 7 are the number 10 raised to the appropriate table entry for the given wavelength and particle, multiplied by the product of π and the values of α for that particle (obtained from NAM6, however), and then summed over all the particles.

Table 7. Values of extinction in Mm^{-1} produced by two different versions of NAM for the four test cases. "Tables" refers to results inferred from tables inside the source code for NOVAM. "NAM6" refers to results given by this code.

Sea	λ	Tables	NAM6
Low	Vis	3.382	3.6037
Low	IR	1.046	1.2398
High	Vis	760.79	780.00
High	IR	48.836	48.956

11. THE INPUT FILE

The input file must be named "In.txt".

Entries on the zeroth line of the input file are in fixed format. That means that all numbers must be correctly located in their proper positions within the zeroth line. If they are not, the program will not run correctly. Subsequent lines are in a free format; all that is required is that spaces separate each entry.

The zeroth line of the input file contains two parameters that I have not yet discussed. These are "Lbug" and "Lcheck". They are integers, set either to 1 or 0, that control the condition and printing status of an optional output file.

When "Lbug" is set to 1, then the file "Debug.txt" is printed out. It is based on the parameters of the first NAM input line. It contains details of the particle concentration, the various losses incurred during integration, and the way the distribution, its second moment, and the Mie extinction factor depend on particle radius. Furthermore, if "Lcheck" is set to 1 when "Lbug" is also set to 1, the file "Debug.txt" will pertain to particle concentrations of 1 per cm^3, regardless of the entries for p, W, and w on the first line of the input file. This is useful for examining properties of the second moment.

Appendix C shows the top section of a sample debug file. This file corresponds to the sample input file in appendix A.

The zeroth-input line has the following form:

```
Lamba     Imax     Lbug     Lcheck     Kmax     Z

FORMAT (F10.5, 4I10, F10.5)
```

Here "Lambda" is the optical wavelength in μm, "Imax" is the total number of lines in the input file after the zeroth, "Lbug" controls the printing of the optional output file, "Lcheck" sets the particle concentrations to unity in that file, "Kmax" is the number of logarithmic steps in particle radius that controls precision, and "Z" is the argument of the complementary error function that controls truncation. Only the first two parameters are required.

Subsequent lines of the input file have the form

```
Time     p     W     w     U

READ (M, *)
```

"*Time*" is a dummy parameter that may be thought of either as the actual time of the observation or merely as a line index. It plays no role in the calculation: whatever appears in this location is merely read in and then read out again. The remaining entries are "p," the air mass parameter (dimensionless); "W," the average wind speed during the previous 24 hours (m s^{-1}); "w," the current wind speed (m s^{-1}); and U, the relative humidity (%). All of these parameters are required.

12. CONCLUSION

NAM6 is a batch program that computes the optical properties of the aerosol size distribution dictated by version 6 of the Navy Aerosol Model. This model describes marine aerosols close to the surface of the open ocean.

The size distribution in this model is determined by the air mass parameter, the average wind speed during the previous 24 hours, the current wind speed, and the relative humidity. Each line of the batch input file contains these four parameters. The program reads each input line, computes the size distribution, and derives the optical properties according to Mie theory for spherical particles. For each input line, NAM6 writes an output line containing the original four parameters plus the total extinction coefficient, the extinction coefficient for scattering, and the forward lobe of the phase function.

The Mie results are obtained through a subroutine MIEV0 written by Warren J. Wiscombe (Wiscombe, 1979).

Look-up tables are not used in this program.

When NAM6 runs on a 333 MHz Pentium II computer, an input file containing 1000 lines will execute in slightly less than 1 minute. This speed is obtained with default precision settings for which I estimate the absolute accuracy to be about 5% for extinction and about 10% for phase. Program precision is under the control of the user, however, and accuracy may be increased, up to a point, by increasing precision and sacrificing speed.

13. REFERENCES

Evans, M., N. Hastings, and B. Peacock. 1993. *Statistical Distributions*. Wiley, New York, NY.

Hinds, W. C. 1982. *Aerosol Technology. Properties, Behavior, and Measurement of Airborne Particles.* Wiley, New York, NY.

Gathman, S. G. 1983. "Optical Properties of the Marine Aerosol as Predicted by the Navy Aerosol Model," *Opt. Eng.*, vol. 22, pp. 57–62.

Gathman, S. G. and K. L. Davidson. 1993. "The Navy Oceanic Vertical Aerosol Model," NRaD Technical Report 1634, Naval Command, Control and Ocean Surveillance Center, RDT&E Division,* San Diego, CA.

Gerber, H. E. 1985. "Relative Humidity Parameterization of the Navy Aerosol Model (NAM)," NRL Report 8956, p. 11. Naval Research Laboratory, Washington, DC

Hale, G. M. and M. R. Query. 1973. "Optical Constants of Water in the 200-nm to 200-μm Wavelength Region," *Applied Optics,* vol. 12, pp. 555–563. The water index used in this program is taken from table 1 on page 557.

Hänel, G. 1971. "The Properties of Atmospheric Aerosol Particles as Functions of the Relative Humidity at Thermodynamic Equilibrium with the Surrounding Moist Air," *Contrib. Atmos. Phys.*, vol. 44, pp. 73–183.

Shettle, E. P. and R. W. Fenn. 1979. "Models for the Aerosols of the Lower Atmosphere and the Effects of Humidity Variations on Their Optical Properties," AFGL-TR-79-0214, Environmental Research Papers No. 676, AFGL, Hanscom AFB, MA 01731. The dust index used in this program is taken from the "Dust-Like" column of table 3 on page 18. The sea salt index used in this program is taken from the "Oceanic, RH = 0%" column of table 6 on page 29.

Wiscombe, W. J. 1979. "Mie Scattering Calculations: Advances in Technique and Fast, Vector-Speed Computer Codes." Technical Note NCAR/TN-140+STR, National Center for Atmospheric Research, Bounder, CO.

van de Hulst, H. C. 1981. *Light Scattering by Small Particles*. Dover, New York, NY.

Volz, F. E. 1972. "Infrared Refractive Index of Atmospheric Aerosol Substances," *Applied Optics*, vol. 11, pp. 755–759. The B1 aerosol index used in this program was taken from figures 2 and 3 by magnifying the figures and scaling the curves with a ruler.

* Now SSC San Diego.

APPENDIX A: SAMPLE INPUT FILE "In.txt"

```
10.591      10       1       0       0       0
 283.1       1      10      10      80
 283.2       2      10      10      80
 283.3       3      10      10      80
 283.4       4      10      10      80
 283.5       5      10      10      80
 283.6       6      10      10      80
 283.7       7      10      10      80
 283.8       8      10      10      80
 283.9       9      10      10      80
 284.0      10      10      10      80
```

APENDIX B: SAMPLE OUTPUT FILE “Out.txt”

```
Wavelength  10.591 microns.     Second moment loss  2.49 %

   Time         a        W        w        U      Bext        Bsca        Pfor
   (--)       (--)   (m s-1)  (m s-1)    (%)    (Mm-1)      (Mm-1)      (sr-1)
 283.1000      1.0     10.0     10.0      80   1.275E+01   7.039E+00   6.342E+00
 283.2000      2.0     10.0     10.0      80   1.284E+01   7.041E+00   6.342E+00
 283.3000      3.0     10.0     10.0      80   1.298E+01   7.044E+00   6.342E+00
 283.4000      4.0     10.0     10.0      80   1.317E+01   7.049E+00   6.342E+00
 283.5000      5.0     10.0     10.0      80   1.343E+01   7.055E+00   6.342E+00
 283.6000      6.0     10.0     10.0      80   1.412E+01   7.064E+00   6.468E+00
 283.7000      7.0     10.0     10.0      80   1.462E+01   7.073E+00   6.468E+00
 283.8000      8.0     10.0     10.0      80   1.521E+01   7.084E+00   6.468E+00
 283.9000      9.0     10.0     10.0      80   1.586E+01   7.096E+00   6.468E+00
 284.0000     10.0     10.0     10.0      80   1.660E+01   7.109E+00   6.468E+00
```

APPENDIX C: TOP PART OF A SAMPLE DEBUG FILE

Version Six of the Navy Aerosol Model

Particle 0 is dry dust with a mode of 0.03 microns.
Particle 1 is wet B1 with a neutral mode of 0.03 microns.
Particle 2 is wet salt with a neutral mode of 0.24 microns.
Particle 3 is wet salt with a neutral mode of 2.00 microns.

Wavelength 10.591 um

Logarithmic steps across the 2nd moment with:

Number of steps	400 (before truncation)
Partition loss	1.40 %
Truncation argument	1.8000
Truncation loss	1.09 %
Number of steps	257 (after truncation)

Air mass parameter	1.0
Average wind speed	10.0 m s-1
Current wind speed	10.0 m s-1
Relative humidity	80 %

Particle	N (cm-3)	Mode (um)	2nd_Moment (Mm-1)	Alpha (cm-3 um-1)
1	1.3655E+02	2.989266E-02	9.015916E-01	2.007144E+03
2	2.4991E+01	2.403115E-01	1.066415E+01	4.569464E+01
3	2.8720E-02	2.002285E+00	8.507924E-01	6.302441E-03

For a radius of 2 microns X is 1.187 and MIEV0 returns:

Particle	Real (--)	Imaginary (--)	Qext (--)	Qsca (--)	Pfor (sr-1)
1	1.556	5.057E-02	6.3345E-01	4.4930E-01	2.1972E-01
2	1.293	5.124E-02	2.9937E-01	1.2658E-01	2.0959E-01
3	1.287	5.232E-02	2.9751E-01	1.2155E-01	2.0947E-01

For particle 1:

K	r (um)	dNdr (cm-3 um-1)	Sum (cm-3)	r2dNdr (cm-3 um)	Sum (Mm-1)	X (--)	Qext (--)	r2dNdrQ (cm-3 um)	Sum (Mm-1)
1	0.0221	1.834E+03	0.000E+00	8.996E-01	0.000E+00	1.314E-02	1.269E-03	1.142E-03	0.000E+00
2	0.0225	1.850E+03	5.751E-01	9.328E-01	2.860E-04	1.332E-02	1.287E-03	1.201E-03	3.656E-07
3	0.0228	1.864E+03	1.163E+00	9.668E-01	5.867E-04	1.351E-02	1.305E-03	1.262E-03	7.554E-07
4	0.0231	1.878E+03	1.764E+00	1.002E+00	9.027E-04	1.370E-02	1.324E-03	1.326E-03	1.171E-06
5	0.0234	1.891E+03	2.377E+00	1.037E+00	1.235E-03	1.389E-02	1.342E-03	1.392E-03	1.613E-06
6	0.0238	1.904E+03	3.004E+00	1.074E+00	1.583E-03	1.409E-02	1.361E-03	1.462E-03	2.085E-06
7	0.0241	1.916E+03	3.643E+00	1.111E+00	1.949E-03	1.429E-02	1.380E-03	1.534E-03	2.586E-06
8	0.0244	1.927E+03	4.296E+00	1.150E+00	2.333E-03	1.449E-02	1.400E-03	1.609E-03	3.120E-06
9	0.0248	1.937E+03	4.961E+00	1.189E+00	2.736E-03	1.469E-02	1.420E-03	1.687E-03	3.687E-06
10	0.0251	1.947E+03	5.639E+00	1.229E+00	3.158E-03	1.490E-02	1.440E-03	1.769E-03	4.291E-06

APPENDIX D: OPTICAL INDEX OF DUST BETWEEN 0.2 AND 40 μm

Lambda	n	n'
0.2000	1.530	7.00E-2
0.2500	1.530	3.00E-2
0.3000	1.530	8.00E-3
0.3371	1.530	8.00E-3
0.4000	1.530	8.00E-3
0.4880	1.530	8.00E-3
0.5145	1.530	8.00E-3
0.5500	1.530	8.00E-3
0.6328	1.530	8.00E-3
0.6943	1.530	8.00E-3
0.8600	1.520	8.00E-3
1.0600	1.520	8.00E-3
1.3000	1.460	8.00E-3
1.5360	1.400	8.00E-3
1.8000	1.330	8.00E-3
2.0000	1.260	8.00E-3
2.2500	1.220	9.00E-3
2.5000	1.180	9.00E-3
2.7000	1.180	1.30E-2
3.0000	1.160	1.20E-2
3.2000	1.220	1.00E-2
3.3923	1.260	1.30E-2
3.5000	1.280	1.10E-2
3.7500	1.270	1.10E-2
4.0000	1.260	1.20E-2
4.5000	1.260	1.40E-2
5.0000	1.250	1.60E-2
5.5000	1.220	2.10E-2
6.0000	1.150	3.70E-2
6.2000	1.140	3.90E-2
6.5000	1.130	4.20E-2
7.2000	1.400	5.50E-2
7.9000	1.150	4.00E-2
8.2000	1.130	7.40E-2
8.5000	1.300	9.00E-2
8.7000	1.400	1.00E-1
9.0000	1.700	1.40E-1
9.2000	1.720	1.50E-1
9.5000	1.730	1.62E-1
9.8000	1.740	1.62E-1
10.000	1.750	1.62E-1
10.591	1.620	1.20E-1
11.000	1.620	1.05E-1
11.500	1.590	1.00E-1
12.500	1.510	9.00E-2
13.000	1.470	1.00E-1
14.000	1.520	8.52E-2
14.800	1.570	1.00E-1
15.000	1.570	1.00E-1
16.400	1.600	1.00E-1
17.200	1.630	1.00E-1
18.000	1.640	1.15E-1

18.500	1.640	1.20E-1
20.000	1.680	2.20E-1
21.300	1.770	2.80E-1
22.500	1.900	2.80E-1
25.000	1.970	2.40E-1
27.900	1.890	3.20E-1
30.000	1.800	4.20E-1
35.000	1.900	5.00E-1
40.000	2.100	6.00E-1

APPENDIX E: OPTICAL INDEX OF B1 AEROSOL BETWEEN 0.2 AND 40 μm

Lambda	n	n'
0.2000	1.392	1.15E-5
0.2250	1.392	1.24E-5
0.2500	1.392	1.33E-5
0.2750	1.392	1.44E-5
0.3000	1.392	1.55E-5
0.3250	1.392	1.67E-5
0.3500	1.392	1.80E-5
0.3750	1.392	1.94E-5
0.4000	1.392	2.09E-5
0.4250	1.392	2.25E-5
0.4500	1.392	2.43E-5
0.4750	1.392	2.62E-5
0.5000	1.392	2.82E-5
0.5250	1.392	3.04E-5
0.5500	1.392	3.27E-5
0.5750	1.392	3.53E-5
0.6000	1.392	3.80E-5
0.6250	1.392	4.10E-5
0.6500	1.392	4.42E-5
0.6750	1.392	4.76E-5
0.7000	1.392	5.13E-5
0.7250	1.392	5.53E-5
0.7500	1.392	5.96E-5
0.7750	1.392	6.42E-5
0.8000	1.392	6.92E-5
0.8250	1.392	7.46E-5
0.8500	1.392	8.04E-5
0.8750	1.392	8.66E-5
0.9000	1.392	9.33E-5
0.9250	1.392	1.01E-4
0.9500	1.392	1.08E-4
0.9750	1.392	1.17E-4
1.00	1.392	1.26E-4
1.20	1.392	2.29E-4
1.40	1.392	4.17E-4
1.60	1.392	5.62E-4
1.80	1.392	1.38E-3
2.00	1.392	2.51E-3
2.20	1.392	4.57E-3
2.40	1.392	8.32E-3
2.60	1.392	1.35E-2
2.65	1.392	1.84E-2
2.70	1.391	0.0244
2.75	1.388	0.0288
2.80	1.386	0.0300
2.85	1.383	0.0289
2.90	1.382	0.0274
2.95	1.381	0.0241
3.00	1.386	0.0209
3.05	1.390	0.0184
3.10	1.393	0.0167
3.15	1.396	0.0156

3.20	1.402	0.0144
3.25	1.408	0.0133
3.30	1.413	0.0124
3.35	1.420	0.0114
3.40	1.426	0.0105
3.45	1.433	0.0097
3.50	1.440	0.0090
3.6	1.448	0.00809
3.7	1.452	0.00686
3.8	1.455	0.00615
3.9	1.458	0.00568
4.0	1.464	0.00560
4.1	1.469	0.00573
4.2	1.475	0.00598
4.3	1.481	0.00622
4.4	1.487	0.00653
4.5	1.490	0.00695
4.6	1.493	0.00749
4.7	1.497	0.00806
4.8	1.500	0.00867
4.9	1.502	0.00929
5.0	1.505	0.0101
5.1	1.508	0.0110
5.2	1.510	0.0122
5.3	1.511	0.0136
5.4	1.505	0.0154
5.5	1.500	0.0181
5.6	1.500	0.0210
5.7	1.500	0.0254
5.8	1.505	0.0311
5.9	1.510	0.0396
6.0	1.519	0.0461
6.1	1.527	0.0474
6.2	1.532	0.0365
6.3	1.536	0.0305
6.4	1.536	0.0279
6.5	1.535	0.0280
6.6	1.527	0.0299
6.7	1.515	0.0326
6.8	1.477	0.0379
6.9	1.447	0.0510
7.0	1.442	0.0551
7.1	1.454	0.0493
7.2	1.492	0.0464
7.3	1.557	0.0438
7.4	1.571	0.0410
7.5	1.580	0.0392
7.6	1.585	0.0387
7.7	1.584	0.0394
7.8	1.581	0.0406
7.9	1.572	0.0438
8.0	1.561	0.0483
8.2	1.476	0.0649
8.4	1.456	0.0841
8.6	1.601	0.0970
8.8	1.774	0.1022
9.0	1.861	0.1092

9.2	1.907	0.1211
9.4	1.919	0.0944
9.6	1.885	0.0916
9.8	1.840	0.0646
10.0	1.818	0.0532
10.5	1.783	0.0398
11.0	1.741	0.0313
11.5	1.712	0.0301
12.0	1.698	0.0389
12.5	1.694	0.0442
13.0	1.690	0.0461
13.5	1.697	0.0478
14.0	1.696	0.0493
14.5	1.669	0.0504
15.0	1.679	0.0668
15.5	1.773	0.0722
16.0	1.812	0.0777
16.5	1.811	0.0832
17.0	1.809	0.1072
17.5	1.808	0.1091
18.0	1.807	0.1083
18.5	1.806	0.1075
19.0	1.804	0.1055
19.5	1.806	0.1035
20.0	1.808	0.1022
21.0	1.812	0.1048
22	1.816	0.1099
23	1.820	0.1176
24	1.817	0.1252
25	1.815	0.1337
26	1.812	0.1422
27	1.809	0.1497
28	1.808	0.1609
29	1.808	0.1722
30	1.808	0.1813
32	1.811	0.2081
34	1.817	0.2390
36	1.823	0.2744
38	1.820	0.3150
40	1.820	0.3617

APPENDIX F: OPTICAL INDEX OF SEA SALT BETWEEN 0.2 AND 40 μm

Lambda	n	n'
0.2000	1.510	1.00E-4
0.2500	1.510	5.00E-6
0.3000	1.510	2.00E-6
0.3371	1.510	4.00E-7
0.4000	1.500	3.00E-8
0.4880	1.500	2.00E-8
0.5145	1.500	1.00E-8
0.5500	1.500	1.00E-8
0.6328	1.490	2.00E-8
0.6943	1.490	1.00E-7
0.8600	1.480	3.00E-6
1.0600	1.470	2.00E-4
1.3000	1.470	4.00E-4
1.5360	1.460	6.00E-4
1.8000	1.450	8.00E-4
2.0000	1.450	1.00E-3
2.2500	1.440	2.00E-3
2.5000	1.430	4.00E-3
2.7000	1.400	7.00E-3
3.0000	1.610	1.00E-2
3.2000	1.490	3.00E-3
3.3923	1.480	2.30E-3
3.5000	1.480	1.60E-3
3.7500	1.470	1.40E-3
4.0000	1.480	1.40E-3
4.5000	1.490	1.40E-3
5.0000	1.470	2.50E-3
5.5000	1.420	3.60E-3
6.0000	1.410	1.10E-2
6.2000	1.600	2.20E-2
6.5000	1.460	5.00E-3
7.2000	1.420	7.00E-3
7.9000	1.400	1.30E-2
8.2000	1.420	2.00E-2
8.5000	1.480	2.60E-2
8.7000	1.600	3.00E-2
9.0000	1.650	2.80E-2
9.2000	1.610	2.60E-2
9.5000	1.580	1.80E-2
9.8000	1.560	1.60E-2
10.000	1.540	1.50E-2
10.591	1.500	1.40E-2
11.000	1.480	1.40E-2
11.500	1.480	1.40E-2
12.500	1.420	1.60E-2
13.000	1.410	1.80E-2
14.000	1.410	2.30E-2
14.800	1.430	3.00E-2
15.000	1.450	3.50E-2
16.400	1.560	9.00E-2
17.200	1.740	1.20E-1
18.000	1.780	1.30E-1

18.500	1.770	1.35E-1
20.000	1.760	1.52E-1
21.300	1.760	1.65E-1
22.500	1.760	1.80E-1
25.000	1.760	2.05E-1
27.000	1.770	2.75E-1
30.000	1.770	3.00E-1
35.000	1.760	5.00E-1
40.000	1.740	1.00E-0

APPENDIX G: OPTICAL INDEX OF WATER BETWEEN 0.2 AND 40 μm

Lambda	n	n'
0.2000	1.396	1.10E-7
0.2250	1.373	4.90E-8
0.2500	1.362	3.35E-8
0.2750	1.354	2.35E-8
0.3000	1.349	1.60E-8
0.3250	1.346	1.08E-8
0.3500	1.343	6.50E-9
0.3750	1.341	3.50E-9
0.4000	1.339	1.86E-9
0.4250	1.338	1.30E-9
0.4500	1.337	1.02E-9
0.4750	1.336	9.35E-10
0.5000	1.335	1.00E-9
0.5250	1.334	1.32E-9
0.5500	1.333	1.96E-9
0.5750	1.333	3.60E-9
0.6000	1.332	1.09E-8
0.6250	1.332	1.39E-8
0.6500	1.331	1.64E-8
0.6750	1.331	2.23E-8
0.7000	1.331	3.35E-8
0.7250	1.330	9.15E-8
0.7500	1.330	1.56E-7
0.7750	1.330	1.48E-7
0.8000	1.329	1.25E-7
0.8250	1.329	1.82E-7
0.8500	1.329	2.93E-7
0.8750	1.328	3.91E-7
0.9000	1.328	4.86E-7
0.9250	1.328	1.06E-6
0.9500	1.327	2.93E-6
0.9750	1.327	3.48E-6
1.00	1.327	2.89E-6
1.20	1.324	9.89E-6
1.40	1.321	1.38E-4
1.60	1.317	8.55E-5
1.80	1.312	1.15E-4
2.00	1.306	1.10E-3
2.20	1.296	2.89E-4
2.40	1.279	9.56E-4
2.60	1.242	3.17E-3
2.65	1.219	6.70E-3
2.70	1.188	0.019
2.75	1.157	0.059
2.80	1.142	0.115
2.85	1.149	0.185
2.90	1.201	0.268
2.95	1.292	0.298
3.00	1.371	0.272
3.05	1.426	0.240
3.10	1.467	0.192
3.15	1.483	0.135

3.20	1.478	0.0924
3.25	1.467	0.0610
3.30	1.450	0.0368
3.35	1.432	0.0261
3.40	1.420	0.0195
3.45	1.410	0.0132
3.50	1.400	0.0094
3.6	1.385	0.00515
3.7	1.374	0.00360
3.8	1.364	0.00340
3.9	1.357	0.00380
4.0	1.351	0.00460
4.1	1.346	0.00562
4.2	1.342	0.00688
4.3	1.338	0.00845
4.4	1.334	0.0103
4.5	1.332	0.0134
4.6	1.330	0.0147
4.7	1.330	0.0147
4.8	1.330	0.0150
4.9	1.328	0.0137
5.0	1.325	0.0124
5.1	1.322	0.0111
5.2	1.317	0.0101
5.3	1.312	0.0098
5.4	1.305	0.0103
5.5	1.298	0.0116
5.6	1.289	0.0142
5.7	1.277	0.0203
5.8	1.262	0.0330
5.9	1.248	0.0622
6.0	1.265	0.107
6.1	1.319	0.131
6.2	1.363	0.0880
6.3	1.357	0.0570
6.4	1.347	0.0449
6.5	1.339	0.0392
6.6	1.334	0.0356
6.7	1.329	0.0337
6.8	1.324	0.0327
6.9	1.321	0.0322
7.0	1.317	0.0320
7.1	1.314	0.0320
7.2	1.312	0.0321
7.3	1.309	0.0322
7.4	1.307	0.0324
7.5	1.304	0.0326
7.6	1.302	0.0328
7.7	1.299	0.0331
7.8	1.297	0.0335
7.9	1.294	0.0339
8.0	1.291	0.0343
8.2	1.286	0.0351
8.4	1.281	0.0361
8.6	1.275	0.0372
8.8	1.269	0.0385
9.0	1.262	0.0399

9.2	1.255	0.0415
9.4	1.247	0.0433
9.6	1.239	0.0454
9.8	1.229	0.0479
10.0	1.218	0.0508
10.5	1.185	0.0662
11.0	1.153	0.0968
11.5	1.126	0.142
12.0	1.111	0.199
12.5	1.123	0.259
13.0	1.146	0.305
13.5	1.177	0.343
14.0	1.210	0.370
14.5	1.241	0.388
15.0	1.270	0.402
15.5	1.297	0.414
16.0	1.325	0.422
16.5	1.351	0.428
17.0	1.376	0.429
17.5	1.401	0.429
18.0	1.423	0.426
18.5	1.443	0.421
19.0	1.461	0.414
19.5	1.476	0.404
20.0	1.480	0.393
21.0	1.487	0.382
22	1.500	0.373
23	1.511	0.367
24	1.521	0.361
25	1.531	0.356
26	1.539	0.350
27	1.545	0.344
28	1.549	0.338
29	1.551	0.333
30	1.551	0.328
32	1.546	0.324
34	1.536	0.329
36	1.527	0.343
38	1.522	0.361
40	1.519	0.385

APPENDIX H: NAM6 SOURCE CODE

```
C     Last change:  CZ   21 Jul 1999    3:06 pm

      PROGRAM NAM6

*************************************************************************
*                                                                       *
*   Carl Zeisse                                                         *
*   Propagation Division D883                                           *
*   SSC SD                                                              *
*   49170 Propagation Path                                              *
*   San Diego, CA 92152-7385                                            *
*                                                                       *
*   The following source code modules are required:                     *
*                                                                       *
*       NAM6.for                                                        *
*       MIEV0.f                                                         *
*       ErrPack.f                                                       *
*       Index.for                                                       *
*       erfc.for                                                        *
*                                                                       *
*   Integer symbols internal to this code are ("NAM6" only):            *
*                                                                       *
*       I      Line number of input file.                               *
*       J      Aerosol particle index (particle number + 1).            *
*       K      Index for ln(r) step.                                    *
*       L      Logical flag.                                            *
*       M      Unit number for input and output files.                  *
*       N      Clock index.                                             *
*                                                                       *
*                                                                       *
*   All lines having to do with program timing have been commented     *
*   out because this code is compiler specific. The user may replace   *
*   these lines with FORTRAN extensions appropriate to his system if   *
*   he so desires.                                                      *
*                                                                       *
*************************************************************************

      DIMENSION Conc(4), Rho(4), P(4), B(4), Alpha(4)
C     INTEGER*4 Nstart, Nend

      PARAMETER (MAXANG = 7, MOMDIM = 200 )
      LOGICAL   ANYANG, PERFCT, PRNT(2)
      INTEGER   IPOLZN, NUMANG, NMOM
      REAL      GQSC, MIMCUT, PMOM(0:MOMDIM, 4), QEXT, QSCA, SPIKE,
     $          XMU(MAXANG)
      COMPLEX   CREFIN, SFORW, SBACK, S1(MAXANG), S2(MAXANG),
     $          TFORW(2), TBACK(2), AerIndex
      COMMON /Gerber/ A(4)
      COMMON /Params/ Mout, J, Wave, pi, U, Rho

      PERFCT  = .FALSE.
      MIMCUT  = 0.0001
      NUMANG  = 0
```

```
      NMOM    = 0
      IPOLZN  = 1234
      ANYANG  = .TRUE.
      PRNT(1) = .FALSE.
      PRNT(2) = .FALSE.

      Minp  = 10                          ! Input file.
      Mout  = 11                          ! Output file.
      Mbug  = 12                          ! Debug file.
C     Mtim  = 13                          ! Timing file.

      e     = EXP(1.)
      pi    = 2. * ASIN(1.)
      Gamma = 1. / (SQRT(pi) * EXP(0.25))

      Kmax0 = 400                         ! Default number of ln(r) steps
      Jmin  = 1                           !            before truncation
      Z0    = 1.8                         ! Default argument of erfc

      A(1) = 0.00                         ! First Gerber growth constant
      A(2) = 1.17
      A(3) = 1.83
      A(4) = 1.97
      DATA B/1.E6, 1.87, 5.13, 5.83/      ! Second Gerber growth constant
      DATA P/0.03, 0.03, 0.24, 2.00/      ! Neutral modal radii in microns

      Zmax  = 2.8                         ! Argument of erfc for partitioning
      Ap    = 7.3194334                   !          [0.008% partition error]
      Bp    = 1.7686532                   ! Coeffs. of Table Curve partition
                                          !          error formula
      OPEN (Minp, FILE = 'In.txt')
      OPEN (Mout, FILE = 'Out.txt')
      OPEN (Mbug, FILE = 'Debug.txt')
C     OPEN (Mtim, FILE = 'Time.txt')

      READ  (Minp, 30) Wave, Imax, Lbug, Lcheck, Kmax, Z
          WaveNum = 2. * pi / Wave
          IF (Lbug .LE. 0) THEN
                   Lbug = 0
               ELSE
                   Lbug = 1
          END IF

          IF (Lcheck .LE. 0) THEN
                   Lcheck = 0
               ELSE
                   Lcheck = 1
          END IF

          IF (Kmax .EQ. 0) THEN
                      Kmax = Kmax0
                ELSE IF (Kmax .LT. 10) THEN
                    Kmax = 10
                ELSE IF (Kmax .GT. 10000) THEN
                    Kmax = 10000
          END IF
          Part = 1000. / (Ap + Bp * Kmax)          ! Table Curve fit to
```

```
                                              !    partition error
      IF (Z .LE. 0.) THEN
           Z = Z0
      END IF
                                        ! Cut-off radii for 2nd moment
      dY   = (2. * Zmax) / Kmax         ! Fix step size regardless of
      Ymin = 1.5 - Z                    !           truncation chosen
      Kcut = INT((Z / Zmax) * Kmax)     ! [R = Rho * EXP(Y)]

   IF (Lbug .EQ. 1) THEN
      WRITE (Mbug, 40)
      WRITE (Mbug, 50) Wave, Kmax, Part, Z, 100 .* erfc(Z), Kcut
   END IF

   WRITE (Mout, 100) Wave, Part + 100. * erfc(Z)

C  CALL TIMER (Nstart)                          ! Begin calculation.

   DO I = 1, Imax                               ! For each input line:

      READ (Minp, *) Time, AMP, Wavg, W, U      ! Get input parameters.
          s = U/100.

      IF (AMP .LE. 5.0) THEN                    ! Make up N(J) = Conc(J)
              Conc(1) = 0.
              Jmin = 2
              Conc(2) = 136.55 * AMP**2
          ELSE
              Conc(1) = 0.3 * 136.55 * AMP**2
              Conc(2) = 0.7 * 136.55 * AMP**2
      END IF
      Conc(3) = 0.5462 * MAX(5.866 * (Wavg - 2.2), 0.5)
      Conc(4) = 4.5518 * 10**(0.06 * W - 2.8)

      IF ((I .EQ. 1) .AND. (Lcheck .EQ. 1)) THEN ! Check results in debug
          DO J = Jmin, 4                          ! file by setting log-
              Conc(J) = 1.                        ! normal integrands to 1:
          END DO
      END IF                                      ! Should get moments.

      DO J = Jmin, 4
          IF (J .EQ. 1) THEN                      ! Make up Rho(J).
                 Growth = 1.
              ELSE
                 Growth = (A(J) - s) / (B(J)*(1. - s))
                 Growth = Growth**(1./3.)
          END IF
          Rho(J)   = Growth * P(J)             ! Make up multiplier of
          Alpha(J) = Gamma * Conc(J) / Rho(J)  !           exponential
      END DO                                   ! dNdr = Alpha * exp{-[..]^2}
*-----------------------------------------------------------------------------

      IF ((I .EQ. 1) .AND. (Lbug .EQ. 1)) THEN  ! Print data to debug file
          IF (Lcheck .NE. 1) THEN               !           if necessary
                        WRITE (Mbug, 200) AMP, Wavg, W
              ELSE
                  WRITE (Mbug, 220)
```

```
      END IF
      WRITE (Mbug, 240) INT(U)
      WRITE (Mbug, 300)
      DO J = Jmin, 4
          WRITE (Mbug, 400) J - 1, Conc(J), Rho(J),
+                           Conc(J) * (Rho(J) * e)**2, Alpha(J)
      END DO
      X = WaveNum * 2.
      WRITE (Mbug, 500) X
      DO J = Jmin, 4
          CREFIN = AerIndex(J)
          CALL MIEV0(X, CREFIN, PERFCT, MIMCUT, ANYANG,
+              NUMANG, XMU, NMOM, IPOLZN, MOMDIM, PRNT, QEXT,
+              QSCA, GQSC, PMOM, SFORW, SBACK, S1, S2, TFORW,
+              TBACK, SPIKE)
          WRITE (Mbug, 600) J - 1, AerIndex(J), Qext, Qsca,
+                        (CABS(Sforw))**2 / (pi * X**2 * Qsca)
      END DO
  END IF
*--------------------------------------------------------------------

  Bext = 0.0
  Bsca = 0.0
  Pfor = 0.0
  DO J = Jmin, 4
*--------------------------------------------------------------------

      IF ((I .EQ. 1) .AND. (Lbug .EQ. 1))  THEN
          WRITE(Mbug, 700) J - 1
      END IF
*--------------------------------------------------------------------

      dR   = 0.
      Hext = 0.          ! Extinction integrand
      Hsca = 0.          ! Scattering integrand
      Hfor = 0.          ! Phase function forward lobe integrand
      G    = 0.          ! Integrand for 1st moment of log-normal
      C    = 0.          ! Integrand for 2nd moment of log-normal
      DO K = 1, Kcut
          Ynew = Ymin + (K - 1) * dY
          Rnew = Rho(J) * EXP(Ynew)
          Xnew = WaveNum * Rnew
          CREFIN  = AerIndex(J)
          CALL MIEV0(Xnew, CREFIN, PERFCT, MIMCUT, ANYANG,
+              NUMANG, XMU, NMOM, IPOLZN, MOMDIM, PRNT, QEXT,
+              QSCA, GQSC, PMOM, SFORW, SBACK, S1, S2, TFORW,
+              TBACK, SPIKE)
          Qextnew = Qext
          Qscanew = Qsca
          Ssqrnew = (CABS(Sforw))**2
          Gnew = EXP( - ( LOG(Rnew / Rho(J)) )**2 )
          Hextnew = Rnew**2 * Qextnew * Gnew
          Hscanew = Rnew**2 * Qscanew * Gnew
          Hfornew =           Ssqrnew * Gnew
          IF (K .EQ. 1) THEN
              dR = 0.0
              GO TO 10
```

```
               END IF
               dR = Rnew - Rold
               Hext = Hext + (Hextnew + Hextold) * dR
               Hsca = Hsca + (Hscanew + Hscaold) * dR
               Hfor = Hfor + (Hfornew + Hforold) * dR
*_____________________________________________________________________

   10          IF ((I .EQ. 1) .AND. (Lbug .EQ. 1))  THEN ! Print to debug
                  Cnew = Rnew**2 * Gnew                  !          file.
                  G = G + (Gnew + Gold) * dR
                  C = C + (Cnew + Cold) * dR
                  WRITE (Mbug, 800) K, Rnew, Alpha(J) * Gnew,
    +                Alpha(J) * G / 2., Alpha(J) * Cnew,
    +                Alpha(J) * C / 2., Xnew, Qextnew,
    +                Alpha(J) * Hextnew, Alpha(J) * Hext / 2.
               END IF
*_____________________________________________________________________

               Rold    = Rnew
               Hextold = Hextnew
               Hscaold = Hscanew
               Hforold = Hfornew
               Gold    = Gnew
               Cold    = Cnew
            END DO                                    ! End of K loop:
            Bext = Bext + Alpha(J) * Hext             !   Accumulate sums.
            Bsca = Bsca + Alpha(J) * Hsca
            Pfor = Pfor + Hfor / Hsca
         END DO                                       ! End of J loop:
         Bext = Bext * pi / 2.                        !   Multiply by
         Bsca = Bsca * pi / 2.                        !   constants.
         Pfor = Pfor / (pi * WaveNum**2)
         WRITE (Mout, 900) Time, AMP, Wavg, W, INT(U), Bext, Bsca, Pfor
         Jmin = 1
      END DO                                          ! End of I loop:
                                                      !   Finish calculation.
C     CALL TIMER(Nend)
C        Elapse = (Nend - Nstart)/100.
C        WRITE (Mtim, 1000) Elapse, Imax, 1000. * Elapse / Imax,
C    +                            1000. / Imax * Elapse / 60.
C     CLOSE(Mtim)

      CLOSE(Minp)
      CLOSE(Mout)
      CLOSE(Mbug)
      PRINT *, "Done!"
          READ (5, *)
      STOP

*     ______________________________________________________________
*
*                          FORMAT STATEMENTS
*     ______________________________________________________________

   30 FORMAT (F10.5, 4I10, F10.5)

   40 FORMAT (/, T10,
```

```
     +37HVersion Six of the Navy Aerosol Model, //,
     +51HParticle 0 is dry dust with a mode of 0.03 microns., /,
     +57HParticle 1 is wet B1 with a neutral mode of 0.03 microns., /,
     +59HParticle 2 is wet salt with a neutral mode of 0.24 microns., /,
     +59HParticle 3 is wet salt with a neutral mode of 2.00 microns.)


 50 FORMAT (/, 10HWavelength, F10.3, 3H um, //,
     +       45HLogarithmic steps across the 2nd moment with:, //,
     +       23H    Number of steps    , I5, 20H (before truncation), /,
     +       23H    Partition loss     , F8.2, 2H %, /,
     +       23H    Truncation argument, F7.4, /,
     +       23H    Truncation loss    , F8.2, 2H %, /,
     +       23H    Number of steps    , I5, 19H (after truncation))


100 FORMAT (/,11H Wavelength, F8.3,
     +       32H microns.     Second moment loss, F6.2, 2H %, //,
     +       3X, 4HTime, 7X, 1Ha,  7X, 1HW,  7X, 1Hw, 7X, 1HU,
     +                         5X, 4HBext, 7X, 4HBsca, 7X, 4HPfor, /,
     +       3X, 4H(--), 5X, 4H(--), 3X, 7H(m s-1),  1X, 7H(m s-1),
     +            3X, 3H(%), 3X, 6H(Mm-1), 5X, 6H(Mm-1), 5X, 6H(sr-1))

200 FORMAT (/, 23H     Air mass parameter, F7.1, /,
     +          23H     Average wind speed, F7.1, 6H m s-1, /,
     +          23H     Current wind speed, F7.1, 6H m s-1)

220 FORMAT (/, 39H      Lcheck is 1. All particle concen-, /,
     +          39H      trations have been set to 1 cm-3.)

240 FORMAT    (23H      Relative humidity, I5, 2H %)


300 FORMAT (/,  8HParticle, T20, 1HN, T37, 4HMode, T54,
     +           10H2nd_Moment, T76, 5HAlpha, /,
     +           T18, 6H(cm-3), T37, 4H(um), T56,
     +           6H(Mm-1), T73, 11H(cm-3 um-1))

400 FORMAT (T5, I1, T15, ES10.4, T30, ES15.6, T50, ES15.6, T70,ES15.6)

500 FORMAT (/, 30HFor a radius of 2 microns X is, F7.3,
     +          19H and MIEV0 returns:, //,
     +          8HParticle, 2X, 4HReal, 4X, 9HImaginary,
     +          4X, 4HQext, 8X, 4HQsca, 8X, 4HPfor, /,
     +           10X, 4H(--), 7X, 4H(--),
     +          6X, 4H(--), 8X, 4H(--), 7X, 6H(sr-1))

600 FORMAT (I5, 5X, F5.3, 2X, ES10.3, 3(2X, ES10.4))

700 FORMAT (/, 13HFor particle , I1, 1H:, //, 3X, 1HK, 4X, 1Hr, 6X,
     +       4HdNdr, 7X, 3HSum, 5X, 6Hr2dNdr, 5X, 3HSum, 8X, 1HX,
     +       8X, 4HQext, 5X, 7Hr2dNdrQ, 4X,  3HSum, /, 7X, 4H(um), 1X,
     +       11H(cm-3 um-1), 2X, 6H(cm-3), 2X, 9H(cm-3 um), 2X,
     +       6H(Mm-1), 5X, 4H(--),
     +       6X, 4H(--), 4X, 9H(cm-3 um), 2X, 6H(Mm-1))

800 FORMAT (I4, F8.4, 8ES10.3)
```

```
 900 FORMAT (F8.4, 3F8.1, I7, ES12.3, 2ES11.3)

C 1000 FORMAT (/, 17H   Elapsed time: , F10.4, 2H s, /,
C     +            17HNumber of lines: , I6, /,
C     +            17H  Time per line: , ES10.4, 3H ms, /,
C     +            17H Time per kline: , F6.1, 8H minutes)

      END


 C     Last change:  CZ    9 Jul 1999    2:50 pm

       FUNCTION AerIndex (J)

 ************************************************************************
 *                                                                      *
 *  Returns the complex refractive index of NAM particle J (or          *
 *  component J) at optical wavelength W (in microns) when the          *
 *  relative humidity is U (in %). M is the index of the material       *
 *  involved in composing the particle.                                 *
 *                                                                      *
 *                                                     INTERPO-         *
 *       J             PARTICLE           M      GROWTH    LATION       *
 *       1          Dust                  1      None       None        *
 *       2          B1 aerosol + water   2+4     Gerber     Hanel       *
 *       3          Sea salt   + water   3+4     Gerber     Hanel       *
 *       4          Sea salt   + water   3+4     Gerber     Hanel       *
 *                                                                      *
 *                                                                      *
 *  "AerIndex" stands for "Aer(osol) Index."                            *
 *                                                                      *
 *  Uses OptIndex.                                                      *
 *                                                                      *
 ************************************************************************

       COMPLEX AerIndex, OptIndex
       COMMON /Gerber/ A(4)
       COMMON /Params/ Mout, Iaer, W, Pi, U, rho  ! Pass in J as argument

       s = U/100.                          ! Convert to fractional humidity

       SELECT CASE (J)
           CASE (1)
 C               is dust with no growth:
                 AerIndex = OptIndex(1)
           CASE (2)
 C               is B1 aerosol with Gerber growth:
                 Growth = (1. - s)/(1. - (s / A(2)))
                 AerIndex = OptIndex(4)
      +                  + (OptIndex(2) - OptIndex(4)) * Growth
           CASE (3)
 C               is sea salt with Gerber growth:
                 Growth = (1. - s)/(1. - (s / A(3)))
                 AerIndex = OptIndex(4)
      +                  + (OptIndex(3) - OptIndex(4)) * Growth
           CASE (4)
```

```
C             is sea salt with different Gerber growth than case 3:
              Growth = (1. - s)/(1. - (s / A(4)))
              AerIndex = OptIndex(4)
     +                  + (OptIndex(3) - OptIndex(4)) * Growth
          CASE DEFAULT
              AerIndex = (1., 0.)
              WRITE (Mout,
     +            '(32HWarning -- No data for component, I2)') J - 1
              STOP
      END SELECT

      RETURN
      END



      FUNCTION OptIndex (M)

***********************************************************************
*                                                                     *
*  Returns the complex refractive index of material M at optical      *
*  wavelength W (in microns):                                         *
*                                           ARRAY                     *
*      M              COMPONENT             SYMBOL                    *
*      1           Dust                       D                       *
*      2           B1 aerosol                 B                       *
*      3           Sea salt                   S                       *
*      4           Water                      W                       *
*                                                                     *
*                                                                     *
*  Other symbols are "Rn" for the real part of the index and "Rk"     *
*  for the imaginary part of the index.                               *
*                                                                     *
*  The parameter NumX is the size of the index array for material X.  *
*                                                                     *
*  "OptIndex" stands for "Opt(ical refractive) Index."                *
*                                                                     *
*  Uses "Locate" and Interpolate."                                    *
*                                                                     *
***********************************************************************

      PARAMETER (NumD = 61, NumB = 149, NumS = 61, NumW = 149)
      COMPLEX OptIndex
      COMMON /Indices/ Dwave(NumD), Dreal(NumD), Dimag(NumD),
     +                 Bwave(NumB), Breal(NumB), Bimag(NumB),
     +                 Swave(NumS), Sreal(NumS), Simag(NumS),
     +                 Wwave(NumW), Wreal(NumW), Wimag(NumW)
      COMMON /Params/ Iout, Iaer, W, Pi, U, rho

      Wmin   = 0.2
      Wmax   = 40.0
      Wdelta = 0.0001

      IF ((W .LT. Wmin - Wdelta) .OR. (W .GT. Wmax + Wdelta)) THEN
C             wavelength is out of range; set the refractive index to one:
              Rn = 1.
```

```
            Rk = 0.
            WRITE (Iout,
     +       '(49HWarning -- Wavelength out of range in "OptIndex.")')
            STOP
         ELSE
C           use linear interpolation with the proper array:
            SELECT CASE (M)
                CASE (1)
                    CALL Locate (Dwave, NumD, W, K)
                    CALL Interpolate (Dwave, W, K, Dreal, Rn)
                    CALL Interpolate (Dwave, W, K, Dimag, Rk)
                CASE (2)
                    CALL Locate (Bwave, NumB, W, K)
                    CALL Interpolate (Bwave, W, K, Breal, Rn)
                    CALL Interpolate (Bwave, W, K, Bimag, Rk)
                CASE (3)
                    CALL Locate (Swave, NumS, W, K)
                    CALL Interpolate (Swave, W, K, Sreal, Rn)
                    CALL Interpolate (Swave, W, K, Simag, Rk)
                CASE (4)
                    CALL Locate (Wwave, NumW, W, K)
                    CALL Interpolate (Wwave, W, K, Wreal, Rn)
                    CALL Interpolate (Wwave, W, K, Wimag, Rk)
                CASE DEFAULT
                    Rn = 1.
                    Rk = 0.
                    WRITE (Iout,
     +                '(31HWarning -- No data for material, I2)') M
                    STOP
            END SELECT
      END IF

      OptIndex = CMPLX (Rn, Rk)

      RETURN
      END


      SUBROUTINE Locate (xx,n,x,j)

*************************************************************************
*                                                                       *
*     Taken directly from "Numerical Recipes in FORTRAN" by W. H.       *
*     Press, S. A. Teukolsky, W. T. Vetterling, and B. F. Flannery,     *
*     Cambridge University Press, 2nd Ed., 1992.  Cf. p. 110 ff.        *
*                                                                       *
*     xx(1), xx(2),....,xx(n) is a one-dimensional array of length n    *
*     that is monotonic. x is given along with xx and n, and Locate     *
*     returns j such that x is between x(j) and x(j + 1).               *
*                                                                       *
*     USED by OptIndex.                                                 *
*                                                                       *
*************************************************************************

      INTEGER j,n
      REAL x,xx(n)
```

```
      INTEGER jl,jm,ju
      jl=0
      ju=n+1
10    if(ju-jl.gt.1)then
        jm=(ju+jl)/2
        if((xx(n).gt.xx(1)).eqv.(x.gt.xx(jm)))then
          jl=jm
        else
          ju=jm
        endif
      goto 10
      endif
      j=jl
      return
      END


      SUBROUTINE Interpolate (Xarray, X, K, Yarray, Y)

***********************************************************************
*                                                                     *
*     A program to interpolate between two adjacent entries in a pair *
*     of one-dimensional arrays.                                      *
*                                                                     *
*     Taken together, the arrays describe a two-dimensional           *
*     pattern of points; for example, a function that is tabulated    *
*     only at a discrete set of points. The x value of the Ith point  *
*     is stored in Xarray(I) and the y value  is stored in Yarray(I). *
*     This routine returns the Y value of a point whose x value is X. *
*     The value of X is somewhere between Xarray(K) and Xarray(K + 1). *
*                                                                     *
*     Consequently, Y will be somewhere between Yarray(K) and         *
*     Yarray(K + 1).                                                  *
*                                                                     *
*     Used by OptIndex                                                *
*                                                                     *
***********************************************************************

      DIMENSION Xarray(*), Yarray(*)
      F = (X - Xarray(K)) / (Xarray(K + 1) - Xarray(K))
      Y = F * (Yarray(K + 1) - Yarray(K)) + Yarray(K)
      RETURN
      END


      BLOCK DATA Optical

***********************************************************************
*                                                                     *
*     These are arrays of data for the real and imaginary indices of  *
*     four different materials in the visible and infrared spectral   *
*     region. The materials are dust (symbol "D"), B1 aerosol (symbol *
*     "B"), sea salt (symbol "S"), and water (symbol "W").            *
*                                                                     *
*     The first array for each material is the optical wavelength,    *
*     the second is the real part of the index, and the third is the  *
```

```
*     imaginary part of the index.                                       *
*                                                                        *
*     The data for dust are taken from the "Dust-Like" column of Table *
*     3 of E. P. Shettle and R. W. Fenn, "Models for the Aerosols of    *
*     the Lower Atmosphere and the Effects of Humidity Variations on    *
*     Their Optical Properties," AFGL-TR-79-0214, Environmental         *
*     Research Papers No. 676, AFGL, Hanscom AFB, MA 01731, 1979.       *
*                                                                        *
*     The data for the B1 aerosol are taken from figures 2 and 3 of     *
*     F. E. Volz, "Infrared Refractive Index of Atmospheric Aerosol     *
*     Substances," Applied Optics 11, 755-759, 1972. These data were    *
*     scaled with a ruler by S. G Gathman from magnified images he      *
*     made of those figures.                                             *
*                                                                        *
*     The data for sea salt are taken from the "Oceanic, RH=0%"         *
*     column  of Table 6 of Shettle and Fenn.                            *
*                                                                        *
*     The data for water are taken from G. M. Hale and M. R. Querry,    *
*     "Optical Constants of Water in the 200-nm to 200-um Wavelength    *
*     Region," Applied Optics 12, 555-563, 1973.                         *
*                                                                        *
*                                                                        *
*     Used by Locate and Interpolate                                     *
*                                                                        *
**************************************************************************

      PARAMETER (NumD = 61, NumB = 149, NumS = 61, NumW = 149)
      COMMON /Indices/ Dwave(NumD), Dreal(NumD), Dimag(NumD),
     +                 Bwave(NumB), Breal(NumB), Bimag(NumB),
     +                 Swave(NumS), Sreal(NumS), Simag(NumS),
     +                 Wwave(NumW), Wreal(NumW), Wimag(NumW)

      DATA Dwave  /
C     Wavelengths for dust.
     +     0.200,     0.250,     0.300,     0.337,     0.400,     0.488,
     +     0.515,     0.550,     0.633,     0.694,     0.860,     1.060,
     +     1.300,     1.536,     1.800,     2.000,     2.250,     2.500,
     +     2.700,     3.000,     3.200,     3.392,     3.500,     3.750,
     +     4.000,     4.500,     5.000,     5.500,     6.000,     6.200,
     +     6.500,     7.200,     7.900,     8.200,     8.500,     8.700,
     +     9.000,     9.200,     9.500,     9.800,    10.000,    10.591,
     +    11.000,    11.500,    12.500,    13.000,    14.000,    14.800,
     +    15.000,    16.400,    17.200,    18.000,    18.500,    20.000,
     +    21.300,    22.500,    25.000,    27.900,    30.000,    35.000,
     +    40.000/

      DATA Dreal  /
C     Real index for dust.
     +     1.530,     1.530,     1.530,     1.530,     1.530,     1.530,
     +     1.530,     1.530,     1.530,     1.530,     1.520,     1.520,
     +     1.460,     1.400,     1.330,     1.260,     1.220,     1.180,
     +     1.180,     1.160,     1.220,     1.260,     1.280,     1.270,
     +     1.260,     1.260,     1.250,     1.220,     1.150,     1.140,
     +     1.130,     1.400,     1.150,     1.130,     1.300,     1.400,
     +     1.700,     1.720,     1.730,     1.740,     1.750,     1.620,
     +     1.620,     1.590,     1.510,     1.470,     1.520,     1.570,
     +     1.570,     1.600,     1.630,     1.640,     1.640,     1.680,
```

```
     +     1.770,      1.900,      1.970,      1.890,      1.800,      1.900,
     +     2.100/

      DATA Dimag   /
C     Imaginary index for dust.
     + 0.700E-01, 0.300E-01, 0.800E-02, 0.800E-02, 0.800E-02, 0.800E-02,
     + 0.800E-02, 0.800E-02, 0.800E-02, 0.800E-02, 0.800E-02, 0.800E-02,
     + 0.800E-02, 0.800E-02, 0.800E-02, 0.800E-02, 0.900E-02, 0.900E-02,
     + 0.130E-01, 0.120E-01, 0.100E-01, 0.130E-01, 0.110E-01, 0.110E-01,
     + 0.120E-01, 0.140E-01, 0.160E-01, 0.210E-01, 0.370E-01, 0.390E-01,
     + 0.420E-01, 0.550E-01, 0.400E-01, 0.740E-01, 0.900E-01, 0.100E+00,
     + 0.140E+00, 0.150E+00, 0.162E+00, 0.162E+00, 0.162E+00, 0.120E+00,
     + 0.105E+00, 0.100E+00, 0.900E-01, 0.100E+00, 0.852E-01, 0.100E+00,
     + 0.100E+00, 0.100E+00, 0.100E+00, 0.115E+00, 0.120E+00, 0.220E+00,
     + 0.280E+00, 0.280E+00, 0.240E+00, 0.320E+00, 0.420E+00, 0.500E+00,
     + 0.600E+00/

      DATA Bwave   /
C     Wavelengths for B1 aerosol.
     +     0.200,      0.225,      0.250,      0.275,      0.300,      0.325,
     +     0.350,      0.375,      0.400,      0.425,      0.450,      0.475,
     +     0.500,      0.525,      0.550,      0.575,      0.600,      0.625,
     +     0.650,      0.675,      0.700,      0.725,      0.750,      0.775,
     +     0.800,      0.825,      0.850,      0.875,      0.900,      0.925,
     +     0.950,      0.975,      1.000,      1.200,      1.400,      1.600,
     +     1.800,      2.000,      2.200,      2.400,      2.600,      2.650,
     +     2.700,      2.750,      2.800,      2.850,      2.900,      2.950,
     +     3.000,      3.050,      3.100,      3.150,      3.200,      3.250,
     +     3.300,      3.350,      3.400,      3.450,      3.500,      3.600,
     +     3.700,      3.800,      3.900,      4.000,      4.100,      4.200,
     +     4.300,      4.400,      4.500,      4.600,      4.700,      4.800,
     +     4.900,      5.000,      5.100,      5.200,      5.300,      5.400,
     +     5.500,      5.600,      5.700,      5.800,      5.900,      6.000,
     +     6.100,      6.200,      6.300,      6.400,      6.500,      6.600,
     +     6.700,      6.800,      6.900,      7.000,      7.100,      7.200,
     +     7.300,      7.400,      7.500,      7.600,      7.700,      7.800,
     +     7.900,      8.000,      8.200,      8.400,      8.600,      8.800,
     +     9.000,      9.200,      9.400,      9.600,      9.800,     10.000,
     +    10.500,     11.000,     11.500,     12.000,     12.500,     13.000,
     +    13.500,     14.000,     14.500,     15.000,     15.500,     16.000,
     +    16.500,     17.000,     17.500,     18.000,     18.500,     19.000,
     +    19.500,     20.000,     21.000,     22.000,     23.000,     24.000,
     +    25.000,     26.000,     27.000,     28.000,     29.000,     30.000,
     +    32.000,     34.000,     36.000,     38.000,     40.000/

      DATA Breal   /
C     Real index for B1 aerosol.
     +     1.392,      1.392,      1.392,      1.392,      1.392,      1.392,
     +     1.392,      1.392,      1.392,      1.392,      1.392,      1.392,
     +     1.392,      1.392,      1.392,      1.392,      1.392,      1.392,
     +     1.392,      1.392,      1.392,      1.392,      1.392,      1.392,
     +     1.392,      1.392,      1.392,      1.392,      1.392,      1.392,
     +     1.392,      1.392,      1.392,      1.392,      1.392,      1.392,
     +     1.392,      1.392,      1.392,      1.392,      1.392,      1.392,
     +     1.391,      1.388,      1.386,      1.383,      1.382,      1.381,
     +     1.386,      1.390,      1.393,      1.396,      1.402,      1.408,
     +     1.413,      1.420,      1.426,      1.433,      1.440,      1.448,
```

```
     +     1.452,      1.455,      1.458,      1.464,      1.469,      1.475,
     +     1.481,      1.487,      1.490,      1.493,      1.497,      1.500,
     +     1.502,      1.505,      1.508,      1.510,      1.511,      1.505,
     +     1.500,      1.500,      1.500,      1.505,      1.510,      1.519,
     +     1.527,      1.532,      1.536,      1.536,      1.535,      1.527,
     +     1.515,      1.477,      1.447,      1.442,      1.454,      1.492,
     +     1.557,      1.571,      1.580,      1.585,      1.584,      1.581,
     +     1.572,      1.561,      1.476,      1.456,      1.601,      1.774,
     +     1.861,      1.907,      1.919,      1.885,      1.840,      1.818,
     +     1.783,      1.741,      1.712,      1.698,      1.694,      1.690,
     +     1.697,      1.696,      1.669,      1.679,      1.773,      1.812,
     +     1.811,      1.809,      1.808,      1.807,      1.806,      1.804,
     +     1.806,      1.808,      1.812,      1.816,      1.820,      1.817,
     +     1.815,      1.812,      1.809,      1.808,      1.808,      1.808,
     +     1.811,      1.817,      1.823,      1.820,      1.820/

      DATA Bimag  /
C     Imaginary index for B1 aerosol.
     + 0.115E-04, 0.124E-04, 0.133E-04, 0.144E-04, 0.155E-04, 0.167E-04,
     + 0.180E-04, 0.194E-04, 0.209E-04, 0.225E-04, 0.243E-04, 0.262E-04,
     + 0.282E-04, 0.304E-04, 0.327E-04, 0.353E-04, 0.380E-04, 0.410E-04,
     + 0.442E-04, 0.476E-04, 0.513E-04, 0.553E-04, 0.596E-04, 0.642E-04,
     + 0.692E-04, 0.746E-04, 0.804E-04, 0.866E-04, 0.933E-04, 0.101E-03,
     + 0.108E-03, 0.117E-03, 0.126E-03, 0.229E-03, 0.417E-03, 0.562E-03,
     + 0.138E-02, 0.251E-02, 0.457E-02, 0.832E-02, 0.135E-01, 0.184E-01,
     + 0.244E-01, 0.288E-01, 0.300E-01, 0.289E-01, 0.274E-01, 0.241E-01,
     + 0.209E-01, 0.184E-01, 0.167E-01, 0.156E-01, 0.144E-01, 0.133E-01,
     + 0.124E-01, 0.114E-01, 0.105E-01, 0.970E-02, 0.900E-02, 0.809E-02,
     + 0.686E-02, 0.615E-02, 0.568E-02, 0.560E-02, 0.573E-02, 0.598E-02,
     + 0.622E-02, 0.653E-02, 0.695E-02, 0.749E-02, 0.806E-02, 0.867E-02,
     + 0.929E-02, 0.101E-01, 0.110E-01, 0.122E-01, 0.136E-01, 0.154E-01,
     + 0.181E-01, 0.210E-01, 0.254E-01, 0.311E-01, 0.396E-01, 0.461E-01,
     + 0.474E-01, 0.365E-01, 0.305E-01, 0.279E-01, 0.280E-01, 0.299E-01,
     + 0.326E-01, 0.379E-01, 0.510E-01, 0.551E-01, 0.493E-01, 0.464E-01,
     + 0.438E-01, 0.410E-01, 0.392E-01, 0.387E-01, 0.394E-01, 0.406E-01,
     + 0.438E-01, 0.483E-01, 0.649E-01, 0.841E-01, 0.970E-01, 0.102E+00,
     + 0.109E+00, 0.121E+00, 0.944E-01, 0.916E-01, 0.646E-01, 0.532E-01,
     + 0.398E-01, 0.313E-01, 0.301E-01, 0.389E-01, 0.442E-01, 0.461E-01,
     + 0.478E-01, 0.493E-01, 0.504E-01, 0.668E-01, 0.722E-01, 0.777E-01,
     + 0.832E-01, 0.107E+00, 0.109E+00, 0.108E+00, 0.108E+00, 0.105E+00,
     + 0.104E+00, 0.102E+00, 0.105E+00, 0.110E+00, 0.118E+00, 0.125E+00,
     + 0.134E+00, 0.142E+00, 0.150E+00, 0.161E+00, 0.172E+00, 0.181E+00,
     + 0.208E+00, 0.239E+00, 0.274E+00, 0.315E+00, 0.362E+00/

      DATA Swave  /
C     Wavelengths for sea salt.
     +     0.200,      0.250,      0.300,      0.337,      0.400,      0.488,
     +     0.515,      0.550,      0.633,      0.694,      0.860,      1.060,
     +     1.300,      1.536,      1.800,      2.000,      2.250,      2.500,
     +     2.700,      3.000,      3.200,      3.392,      3.500,      3.750,
     +     4.000,      4.500,      5.000,      5.500,      6.000,      6.200,
     +     6.500,      7.200,      7.900,      8.200,      8.500,      8.700,
     +     9.000,      9.200,      9.500,      9.800,     10.000,     10.591,
     +    11.000,     11.500,     12.500,     13.000,     14.000,     14.800,
     +    15.000,     16.400,     17.200,     18.000,     18.500,     20.000,
     +    21.300,     22.500,     25.000,     27.000,     30.000,     35.000,
     +    40.000/
```

```
      DATA Sreal   /
C     Real index for sea salt.
     +       1.510,       1.510,       1.510,       1.510,       1.500,       1.500,
     +       1.500,       1.500,       1.490,       1.490,       1.480,       1.470,
     +       1.470,       1.460,       1.450,       1.450,       1.440,       1.430,
     +       1.400,       1.610,       1.490,       1.480,       1.480,       1.470,
     +       1.480,       1.490,       1.470,       1.420,       1.410,       1.600,
     +       1.460,       1.420,       1.400,       1.420,       1.480,       1.600,
     +       1.650,       1.610,       1.580,       1.560,       1.540,       1.500,
     +       1.480,       1.480,       1.420,       1.410,       1.410,       1.430,
     +       1.450,       1.560,       1.740,       1.780,       1.770,       1.760,
     +       1.760,       1.760,       1.760,       1.770,       1.770,       1.760,
     +       1.740/

      DATA Simag   /
C     Imaginary index for sea salt.
     + 0.100E-03, 0.500E-05, 0.200E-05, 0.400E-06, 0.300E-07, 0.200E-07,
     + 0.100E-07, 0.100E-07, 0.200E-07, 0.100E-06, 0.300E-05, 0.200E-03,
     + 0.400E-03, 0.600E-03, 0.800E-03, 0.100E-02, 0.200E-02, 0.400E-02,
     + 0.700E-02, 0.100E-01, 0.300E-02, 0.230E-02, 0.160E-02, 0.140E-02,
     + 0.140E-02, 0.140E-02, 0.250E-02, 0.360E-02, 0.110E-01, 0.220E-01,
     + 0.500E-02, 0.700E-02, 0.130E-01, 0.200E-01, 0.260E-01, 0.300E-01,
     + 0.280E-01, 0.260E-01, 0.180E-01, 0.160E-01, 0.150E-01, 0.140E-01,
     + 0.140E-01, 0.140E-01, 0.160E-01, 0.180E-01, 0.230E-01, 0.300E-01,
     + 0.350E-01, 0.900E-01, 0.120E+00, 0.130E+00, 0.135E+00, 0.152E+00,
     + 0.165E+00, 0.180E+00, 0.205E+00, 0.275E+00, 0.300E+00, 0.500E+00,
     + 0.100E+01/

      DATA Wwave   /
C     Wavelengths for water.
     +       0.200,       0.225,       0.250,       0.275,       0.300,       0.325,
     +       0.350,       0.375,       0.400,       0.425,       0.450,       0.475,
     +       0.500,       0.525,       0.550,       0.575,       0.600,       0.625,
     +       0.650,       0.675,       0.700,       0.725,       0.750,       0.775,
     +       0.800,       0.825,       0.850,       0.875,       0.900,       0.925,
     +       0.950,       0.975,       1.000,       1.200,       1.400,       1.600,
     +       1.800,       2.000,       2.200,       2.400,       2.600,       2.650,
     +       2.700,       2.750,       2.800,       2.850,       2.900,       2.950,
     +       3.000,       3.050,       3.100,       3.150,       3.200,       3.250,
     +       3.300,       3.350,       3.400,       3.450,       3.500,       3.600,
     +       3.700,       3.800,       3.900,       4.000,       4.100,       4.200,
     +       4.300,       4.400,       4.500,       4.600,       4.700,       4.800,
     +       4.900,       5.000,       5.100,       5.200,       5.300,       5.400,
     +       5.500,       5.600,       5.700,       5.800,       5.900,       6.000,
     +       6.100,       6.200,       6.300,       6.400,       6.500,       6.600,
     +       6.700,       6.800,       6.900,       7.000,       7.100,       7.200,
     +       7.300,       7.400,       7.500,       7.600,       7.700,       7.800,
     +       7.900,       8.000,       8.200,       8.400,       8.600,       8.800,
     +       9.000,       9.200,       9.400,       9.600,       9.800,      10.000,
     +      10.500,      11.000,      11.500,      12.000,      12.500,      13.000,
     +      13.500,      14.000,      14.500,      15.000,      15.500,      16.000,
     +      16.500,      17.000,      17.500,      18.000,      18.500,      19.000,
     +      19.500,      20.000,      21.000,      22.000,      23.000,      24.000,
     +      25.000,      26.000,      27.000,      28.000,      29.000,      30.000,
     +      32.000,      34.000,      36.000,      38.000,      40.000/
```

```
      DATA Wreal  /
C     Real index for water.
     +     1.396,     1.373,     1.362,     1.354,     1.349,     1.346,
     +     1.343,     1.341,     1.339,     1.338,     1.337,     1.336,
     +     1.335,     1.334,     1.333,     1.333,     1.332,     1.332,
     +     1.331,     1.331,     1.331,     1.330,     1.330,     1.330,
     +     1.329,     1.329,     1.329,     1.328,     1.328,     1.328,
     +     1.327,     1.327,     1.327,     1.324,     1.321,     1.317,
     +     1.312,     1.306,     1.296,     1.279,     1.242,     1.219,
     +     1.188,     1.157,     1.142,     1.149,     1.201,     1.292,
     +     1.371,     1.426,     1.467,     1.483,     1.478,     1.467,
     +     1.450,     1.432,     1.420,     1.410,     1.400,     1.385,
     +     1.374,     1.364,     1.357,     1.351,     1.346,     1.342,
     +     1.338,     1.334,     1.332,     1.330,     1.330,     1.330,
     +     1.328,     1.325,     1.322,     1.317,     1.312,     1.305,
     +     1.298,     1.289,     1.277,     1.262,     1.248,     1.265,
     +     1.319,     1.363,     1.357,     1.347,     1.339,     1.334,
     +     1.329,     1.324,     1.321,     1.317,     1.314,     1.312,
     +     1.309,     1.307,     1.304,     1.302,     1.299,     1.297,
     +     1.294,     1.291,     1.286,     1.281,     1.275,     1.269,
     +     1.262,     1.255,     1.247,     1.239,     1.229,     1.218,
     +     1.185,     1.153,     1.126,     1.111,     1.123,     1.146,
     +     1.177,     1.210,     1.241,     1.270,     1.297,     1.325,
     +     1.351,     1.376,     1.401,     1.423,     1.443,     1.461,
     +     1.476,     1.480,     1.487,     1.500,     1.511,     1.521,
     +     1.531,     1.539,     1.545,     1.549,     1.551,     1.551,
     +     1.546,     1.536,     1.527,     1.522,     1.519/

      DATA Wimag  /
C     Imaginary index for water.
     + 0.110E-06, 0.490E-07, 0.335E-07, 0.235E-07, 0.160E-07, 0.108E-07,
     + 0.650E-08, 0.350E-08, 0.186E-08, 0.130E-08, 0.102E-08, 0.935E-09,
     + 0.100E-08, 0.132E-08, 0.196E-08, 0.360E-08, 0.109E-07, 0.139E-07,
     + 0.164E-07, 0.223E-07, 0.335E-07, 0.915E-07, 0.156E-06, 0.148E-06,
     + 0.125E-06, 0.182E-06, 0.293E-06, 0.391E-06, 0.486E-06, 0.106E-05,
     + 0.293E-05, 0.348E-05, 0.289E-05, 0.989E-05, 0.138E-03, 0.855E-04,
     + 0.115E-03, 0.110E-02, 0.289E-03, 0.956E-03, 0.317E-02, 0.670E-02,
     + 0.190E-01, 0.590E-01, 0.115E+00, 0.185E+00, 0.268E+00, 0.298E+00,
     + 0.272E+00, 0.240E+00, 0.192E+00, 0.135E+00, 0.924E-01, 0.610E-01,
     + 0.368E-01, 0.261E-01, 0.195E-01, 0.132E-01, 0.940E-02, 0.515E-02,
     + 0.360E-02, 0.340E-02, 0.380E-02, 0.460E-02, 0.562E-02, 0.688E-02,
     + 0.845E-02, 0.103E-01, 0.134E-01, 0.147E-01, 0.147E-01, 0.150E-01,
     + 0.137E-01, 0.124E-01, 0.111E-01, 0.101E-01, 0.980E-02, 0.103E-01,
     + 0.116E-01, 0.142E-01, 0.203E-01, 0.330E-01, 0.622E-01, 0.107E+00,
     + 0.131E+00, 0.880E-01, 0.570E-01, 0.449E-01, 0.392E-01, 0.356E-01,
     + 0.337E-01, 0.327E-01, 0.322E-01, 0.320E-01, 0.320E-01, 0.321E-01,
     + 0.322E-01, 0.324E-01, 0.326E-01, 0.328E-01, 0.331E-01, 0.335E-01,
     + 0.339E-01, 0.343E-01, 0.351E-01, 0.361E-01, 0.372E-01, 0.385E-01,
     + 0.399E-01, 0.415E-01, 0.433E-01, 0.454E-01, 0.479E-01, 0.508E-01,
     + 0.662E-01, 0.968E-01, 0.142E+00, 0.199E+00, 0.259E+00, 0.305E+00,
     + 0.343E+00, 0.370E+00, 0.388E+00, 0.402E+00, 0.414E+00, 0.422E+00,
     + 0.428E+00, 0.429E+00, 0.429E+00, 0.426E+00, 0.421E+00, 0.414E+00,
     + 0.404E+00, 0.393E+00, 0.382E+00, 0.373E+00, 0.367E+00, 0.361E+00,
     + 0.356E+00, 0.350E+00, 0.344E+00, 0.338E+00, 0.333E+00, 0.328E+00,
     + 0.324E+00, 0.329E+00, 0.343E+00, 0.361E+00, 0.385E+00/

      END
```

```
C     Last change:  CZ   30 Jun 1999    3:02 pm
      FUNCTION erfc(x)

************************************************************************
*                                                                      *
*  Complimentary error function.                                       *
*                                                                      *
*  Use rational approximation 7.1.26 on page 299 of Abramowitz and     *
*  Stegun, "Handbook of Mathematical Functions," volume 55 of NBS      *
*  Applied Mathematical Series, 1964.                                  *
*                                                                      *
************************************************************************

      REAL*8 a1, a2, a3, a4, a5, p, t

      a1 =   0.254829592
      a2 = - 0.284496736
      a3 =   1.421413741
      a4 = - 1.453152027
      a5 =   1.061405429
      p  =   0.3275911

      t  =  1./(1. + p*x)
      erfc = (a1*t + a2*t**2 + a3*t**3 + a4*t**4 + a5*t**5)*EXP(-x**2)

      END
```

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13. ABSTRACT *(Maximum 200 words)*

This report describes the operation of a computer program that calculates optical extinction according to the Navy Aerosol Model (NAM). The Navy Aerosol Model is an empirical model describing the size distribution of aerosol particles close to the surface of the open ocean. The model depends on four parameters: (1) *p*, the dimensionless air mass parameter; (2) *W*, the average wind speed (m s^{-1}) during the previous 24 hours; (3) *w*, the current wind speed (m s^{-1}); and (4) *U*, the relative humidity (%). These parameters completely specify *dN/dr*, the particle size distribution in the Navy Aerosol Model. The information in this report refers solely to the sixth version of the Navy Aerosol Model (NAM6), the version that is the kernel of the Navy Oceanic Vertical Aerosol Model.

When NAM6 runs on a 333 MHz Pentium II computer, an input file containing a thousand lines will execute in slightly less than 1 minute. This speed is obtained with default precision settings for which the absolute accuracy is measured as approximately 5% for extinction and 10% for phase. Program precision is under the control of the user, however, and accuracy may be increased, up to a point, by increasing precision and sacrificing speed.

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